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PUBLICATIONS OF THE GEOLOGICAL SOCIETY OF AMERICA

Regular Publications

The Society issues a single serial octavo publication entitled Bulletin of the Geological Society of America. This serial is made up of *proceedings* and *memoirs*, the former embracing the records of meetings, with abstracts and short papers, list of Fellows, etcetera, and the latter embracing larger papers accepted for pnblication. The matter is issued as rapidly as practicable, in covered brochures, which are at once distributed to Fellows and to such exchanges and subscribers as desire the brochure form of distribution. The brochures are arranged for binding in annual volumes, which are elaborately indexed. To this date eighteen volumes have been published and an index to the first ten volumes.

The Bulletin is sold to Fellows of the Society and to the public either in separate brochures or in complete (unbound) volumes. The *prices* are as follows: To libraries and to persons residing outside of North America, five dollars ($5.00) per volume; to persons in North America not Fellows of the Society, ten dollars ($10.00) per volume (the same amount as the annual dues of the Fellows); to Fellows of the Society, a variable amount, depending upon the cost of publication. These prices cover cost of transmission to all parts of the globe. No reduction is made to dealers. Subscribers should specify whether they desire the brochures or the completed volume. Orders should be addressed to the Secretary, and drafts and money orders made payable to the *Secretarg of the Geological Society of America*, whose address is care of the American Museum of Natural History, New York, N. Y.

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Brochures of Volume 18

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Irregular Publications

In the interest of exact bibliography, the Society takes cognizance of all publications issued wholly or in part under its auspices. Each author of a memoir receives 30 copies without cost, and is permitted to order any additional number at a slight advance on cost of paper and presswork ; and these separate brochures are identical with those of the editions issued and distributed by the Society. Contributors to the proceedings are also authorized to order any number of separate copies of their papers at a slight advance on cost of paper and presswork ; but such separates are bibliographically distinct from the brochures issued by the Society.

The following separates of parts of volume 18 have been issued :

Editions uniform with the Brochures of the Society

Pages	1– 28,		30 copies.	April	5, 1907.
"	29–178,		280 " *	"	9, 1907.
"	179–194,		30 "	May	15, 1907.
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CORRECTIONS AND INSERTIONS

All contributors to volume 18 have been invited to send corrections and insertions to be made in their papers, and the volume has been scanned with some care by the Editor. The following are such corrections and insertions as are deemed worthy of attention :

Page 123, line 7 from top; *for* "1 x 6" *read* IX *b*
" 144, line 2 from bottom; *for* "prediminating" *read* predominating
" 168, line 5 from bottom ; *for* "appears" *read* appear
" 173, line 18 from top; *for* "at the Washington" *read* at the end of the Washington
" 179, foot note; *for* "December 29, 1907," *read* December 29, 1906
" 209, line 5 from bottom, *omit* "all"
" 229, lines 1, 2, and 3 from top; should follow lines 4, 5, 6, and 7
" 234, line 12 from bottom ; *for* "cinders" *read* continents
" 427, foot note; *for* "Received by the Secretary of the Society from the Censor, September 13, 1907," *read* Published by permission of the Director of the U. S. Geological Survey
" 478, line 12 from top; *for* "those in intrusion" *read* those of intrusion

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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CONCENTRATION AS A GEOLOGICAL PRINCIPLE

PRESIDENTIAL ADDRESS BY ISRAEL C. RUSSELL *

(Read before the Society December 27, 1906)

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INTRODUCTION

It is a matter of current knowledge among geologists that various mineral substances of a greater or less degree of purity are at the present

* Owing to the death of President Russell, this paper was read by Acting President Davis.

Manuscript received by the Secretary of the Society December 28, 1906.

time being separated through the agency of natural processes from other substances or gathered from a previously widely disseminated state and placed by themselves. To this general process the term geological concentration has been applied. It is also well known from the study of mineral veins, residual earths, etcetera, that similar processes of concentration have been in operation throughout geological time, and that in obedience to a law of nature, as yet inscutible, whereby like seeks like, most mineral substances of commercial value have been segregated in veins, beds, and other deposits, and thus become available for human uses. No systematic attempt seems to have been made, however, to formulate the many and frequently highly complex processes by which the concentration of mineral substances through the action of natural agencies is brought about. It is with this phase of geological study that the present address is concerned.

Statement of the Problem

During the flow of streams heavier is separated from lighter material in suspension or rolled along the bottom, and gold, platinum, tin ore, and other substances of high specific gravity are frequently retained in depressions of the stream's beds, while substances of less specific gravity are carried on. Water emerging at the earth's surface as springs contains calcium carbonate, silica, etcetera, in solution, which in many instances are deposited as chemical precipitates. Plants select carbon from the carbon dioxide of the air and secrete it in their tissues, thus accumulating material suitable for the production of beds of peat and coal. These and other similar or analogous processes whereby concentration of mineral matter results are now in operation and should, as it seems, to be duly recognized as constituting a distinct and important chapter in dynamical geology.

Under the uniformitarian doctrine that "the present is the key to the past," it is evident that a study of the processes by which the concentration of mineral matter is now being brought about should furnish a means for determining the nature and mode of action of the processes by which similar results were produced during past time. In other words, a knowledge of the processes of concentration now in operation furnishes a means for translating the records of former combinations of agencies and conditions into terms which may be defined by observing the results produced by similar combinations at the present day. In the same manner that ripple-marks, shrinkage cracks, raindrop impressions, etcetera, on ancient sandstones furnish evidence as to the geographical

and physical conditions which prevailed during former stages in the earth's history; and in the same manner, also, that fossils enable one to trace the evolution of species, genera, etcetera, of animals and plants or to follow the migrations of floras and faunas during former geological periods, so a knowledge of present processes of concentration shed light on many pages of geological history which otherwise would remain in shadow. Not only do the principles governing the concentration of mineral matter furnish a tool for use in general geological investigations, but one which is of practical utility to the economic geologist and mining engineer. For example, it is only when the processes of concentration which have led to the formation of a bed of coal or that filled a fissure with ore are understood that predictions worthy the name can be made as to the extent of such deposits or reliable advice given in reference to the localities and associations most suggestive of their presence.

In a preceding paragraph examples of what is meant by the term concentration were cited. One of the processes, namely, the separation of gold, platinum, etcetera, from associated debris is obviously controlled by physical conditions; another, the precipitation of calcium carbonate and silica from the waters of springs, is dependent in part at least on chemical conditions; and still another, the secretion of carbon in the tissues of plants, necessitates the action of vital functions. These illustrations suggest a method for classifying the various processes by which mineral matter is concentrated, thus rendering it practicable to give concrete shape to the tool we wish to fashion. The suggestion is that the many and varied processes by which concentration is brought about may be arranged in orderly sequence with reference to the nature of the chief or controlling force by which the selection, transportation, and deposition of the material segregated is rendered possible.

Analysis of the Processes of Geological Concentration

The activities which lead to the separation of one kind or of a definite combination of matter from other kinds or combinations of matter, the transfer of the selected material to a new locality, or more or less complete isolation of a residue, precipitate, etcetera, are: (1) physical force, (2) chemical force, (3) the intimate and interdependent combination of molecular and atomic activities termed physical-chemical force, and (4) the property inherent in living organisms which is designated as vital force. Under the influence of one or another of these four divisions of energy as a dominant factor, it seems practicable to arrange all the processes of concentration now in operation or which can be shown to

have been formerly active. With this idea in mind, the diverse and frequently highly complex processes of concentration may be conveniently classified as mechanical, chemical, physical-chemical, and vital processes.

To be sure, in attempting to classify the processes whereby concentration is effected, as in most other similar efforts to tabulate natural phenomena, the divisions which it is convenient to establish are largely empirical. The dividing lines are not in all cases definite and sharply defined, but resemble rather the recognition of species among organisms or the partitioning of prairie lands among various owners. In many and perhaps most instances, however, in which natural methods of concentration are in operation, some one physical, chemical, physical-chemical, or vital process is dominant and determines the major characteristics of the resultant product. In the recognition of the dominant factors opinions may differ, as they do concerning species among plants and animals, but this qualification need not detract from the utility of the general principle which it is the purpose of this address to emphasize.

Primary Divisions

It is obvious from current geological knowledge concerning the various processes of erosion, transportation, and deposition that an extensive group of concentrates have resulted mainly and essentially from the mechanical changes which take place on the earth's surface. A typical example is furnished by the way in which dry, heterogeneous debris is separated by the winnowing action of the wind into residual material, too heavy for the wind to move, and graded accumulations formed by the deposition of the transported material. In this process mechanical action, or force, is the dominant agency leading to the results referred to, and all similar processes may be conveniently grouped under the term mechanical concentration.

In a similar manner in many instances chemical changes are in control and lead to the isolation of residual material and the accumulation of graded precipitates or other deposits. In many of the operations of nature, however, which result in concentration the part played by the physical processes and by chemical processes are so equally balanced that no plane of cleavage between the two can be detected. In a manner analogous to the recognition of the science of physical chemistry to embrace the borderland between two long recognized sciences, it seems permissible to differentiate physical and chemical processes of concentration on the one hand from physical-chemical processes on the other. Assistance in this direction may be had by recognizing the dominant

field of action of the three groups of processes under consideration. The field of action of the processes of concentration in which either physical agencies or chemical agencies are in a large majority of instances clearly dominant is the outer portion of the earth and includes the zone of contrast of the atmosphere with the lithosphere and the zone of weathering on the outer earth. The portion of the earth in which physical and chemical agencies favoring concentration go hand in hand and are to a conspicuous degree mutually interdependent has as its superior or outer limit the base of the zone of weathering and includes the zone of concentration and the centrosphere, or the inner earth.

In reference to what is termed above the outer earth, temperature and pressure are low in intensity and have but small yearly fluctuations, but within this narrow boundaries are subject in each instance to rapid fluctuations both at a given locality and from place to place. In the inner earth both temperature and pressure are of a high order of intensity, in each instance increase with depth, and soon reach what may be termed incomprehensible values, but are without yearly variations and during even secular changes are modified but slowly.

In the first of the provinces thus defined, namely, the outer earth, the part played by dominantly chemical and dominantly physical processes of concentration may be differentiated and chemical concentrates given equal rank with the mechanical concentrates.

In the second province, namely, the inner earth, physical conditions, and principally temperature and pressure, are, as nearly as can be judged, equal and perhaps of greater importance than the conditions usually designated as chemical, which bring about concentration. The two, however, are so intimately associated and so thoroughly introactive that their combined influence only can be consistently used as a basis of classification in the present connection. Physical-chemical forces are therefore given equal rank with the dominantly mechanical and dominantly chemical forces which lead to concentration.

Again, under the influence of life, physical and chemical changes are guided by a force not recognizable in the inorganic world, and through its action matter is given an organic structure comparable in rank with the crystalline structure in the inorganic world. Through the dominant action of vital force certain substances are differentiated from other substances and concentrated to form the tissues of plants and animals. Still further concentration by the organic bodies themselves may result by the action of mechanical agencies or from chemical changes, but the accumulations of solid organic debris or of liquids or gases arising from the decomposition of such material when accumulated so as to form a

geological deposit may justly be termed an organic concentrate. Vital force may thus be ranked with mechanical, chemical, and physical-chemical forces as a primary agency leading to the concentration of matter.

Mechanical Concentration

EFFECTS OF GRAVITY

Gravity acting singly, as when talus slopes are formed and avalanches occur, or with assistance of such a transporting agency as is furnished by glaciers, may lead to the concentration of heterogeneous accumulations. When, however, gravity works in conjunction with a transporting agency in a liquid or gaseous condition it is enabled to record a selective power holding certain objects in place while their associates are moved, and during the time the material moved is in transit causing certain portions to come to rest while others are carried on. The media with the aid of which gravitation is enabled to separate more or less perfectly the component parts of heterogeneous mixtures of mineral and rock fragments are principally air and water currents. It is in this connection that the best illustrations of the principles governing mechanical concentration occur.

AIR AND WATER CURRENTS

With the aid of air currents, gravitation causes the separation of lighter from heavier material, of smaller from larger fragments, of rounded from angular grains, etcetera. The material which the wind is capable of removing is more or less completely carried away and a residuum usually remains. Two important phases of the general process of concentration are thus illustrated: first, the concentration of material that is left as residue, owing to the removal of certain varieties of material previously present, and, second, the accumulation of the material removed in more or less perfectly graded deposits.

Examples of mechanical concentration in which air currents are the controlling agency are furnished: first, by the stones, gravel, etcetera, on wind-denuded areas, as desert plains, and, second, accumulations of gravel, sand, and dust, which are formed where wind-transported debris comes to rest. This comprehensive and important process, which has been in operation since debris first became dry on the earth's surface and was moved by the wind, corresponds to the winnowing of chaff from grain. In seeking to supply a knowledge of the principles governing eolian concentration as an aid in discovering products of commercial importance, not only the piles of chaff composing dust, soils, sand dunes,

etcetera, should be examined, but search made for the grain left on wind-swept areas, with the hope of discovering gems and flakes and nuggets of gold, platinum, and other heavy metals and ores.

An important adjunct to the process of eolian concentration is furnished by explosive volcanic eruptions. During such eruptions the ratio of the size, weight, and shape of the fragments blown into the air to the propelling force leads to an assorting of the debris showered on the earth's surface, but assisting this process, and, as it seems, usually assuming the leading role, is the transporting power of air currents. During the operations of either the propelling or carrying agency, however, the selective power of gravity may be credited such assorting as takes place of the material discharged.

With the aid of water currents, gravitation leads to the selection from heterogeneous debris of certain classes of material for transportation and the leaving of other classes of material as residues. Concentration of material, owing to the removal of other kinds of material previously mingled with it, through the combined action of water currents and gravitation, is of the same nature as the similar process already noted in the case of air currents, but from a geological point of view is vastly more important. Examples of residual material concentrated through the agency under consideration are furnished by the boulders and stones in stream beds and on the beaches of the ocean and of lakes, in numerous now abandoned waterways and along ancient coast lines.

In the process of stream and current transportation, mineral and rock fragments carried in suspension or rolled and pushed along the bottom are assorted with reference to size, gravity, and shape and are finally deposited in more or less perfectly assorted accumulations. Witnesses to the importance of this process are furnished on every continent by extensive beds of assorted debris, like gravel, sand, clay, etcetera, and by thick and extensive strata composed of consolidated material of like character. A special phase of the process is illustrated by the manner in which grains and nuggets of gold, platinum, cerussite, etcetera, are concentrated in depressions and crevices in the beds of streams and the current-swept shores of standing water bodies. So well known is the process referred to that it is employed in many ways in the arts, as, for example, the separation of heavy minerals from crushed rock on the concentrating tables used in certain metallurgical operations.

A knowledge of the laws governing transportation by water currents and the secondary or associated conditions which modify their operation is of prime importance in searching for localities where fractional parts of former heterogeneous stream loads have been laid aside. The practical

phases of this far-reaching principle have been worked out in detail by the placer miner.

Modifying the action of gravitation in its selective work when aided by air or water currents is at times the physical condition of the surface over which the currents carry debris. Degree of roughness is here an important and frequently a controlling factor, as is illustrated by the natural riffles which catch and retain grains of gold, but other conditions may favor the exercising of a selective preference. Variations in molecular attraction or adhesion and in chemical affinity between the various fragments transported, or between the material carried and the surface with which it comes in contact, are, as it seems, minor phases of what is in the main a mechanical process. The selective power manifested by mercury for gold in the troughs of the sluices used by placer miners and the peculiar selective property that grease has for the diamond, as illustrated on the concentrating tables used at the South African diamond fields, should lead geologists to look for analogous processes under natural conditions.

ICE CURRENTS

While air and water currents furnish the chief determining or qualifying conditions which cooperate with gravitation in bringing about the mechanical concentration of debris, at least analogous results are produced by ice currents. Glaciers, however, have but little, if any, selective or assorting power, but both the residue they leave—if such a term is permissible in reference to the debris they sometimes pass over without securing—and the deposits they make are characteristically heterogeneous. An assorting of the debris composing surface and marginal moraines does occur, however, owing to the rolling and sliding of the larger or more spherical stones present on steep slopes, and a rude sort of concentration is brought about during the accumulation of moraines; but these minor results of the work of sluggish and inflexible ice currents do not require consideration at this time.

FILTRATION

Associated with the transportation of debris in suspension by water currents is the process of natural filtration. Although this process has received but scant attention from geologists, its functions are evidently of vast importance. The direct influence of filtration in concentrating debris or in leading to the accumulation of material of economic importance is less obvious than the restraining influence it exerts on the

action of agencies tending to remove and perhaps redistribute accumulations of debris brought about in various other ways.

The function of filtration is the separation of solid substances in suspension in liquid from the containing liquid. In all geological processes of this nature the containing liquid is water. Land areas on which rain falls may be considered as filters of vast extent. Rain drops on striking the ground in many instances disturb fine particles on which they impinge and take them into suspension. In fact, the accumulated rain drops gather into surface streams which bear away this freight of silt, but in part the water sinks into the ground and is filtered. When the filter is coarse no material of sufficient fineness to form soil remains, and barren areas of angular rocks, boulder pavements, form the surface. When the filter is of fine texture, however, and when plants assist in binding its particles together, efficient filtration results, as is abundantly proven not only by the conservation of the soil present, but by the clearness of the springs formed when the filtered water emerges once more at the earth's surface. It is to the conservative influence of filtration that the preservation and fertility of soils is largely due. By this same process, also, the beds of streams when of an open texture are rendered impervious. In such instances the meshes of the filter become clogged with the material separated from the water which percolates through them.

Downward percolation favors the solution of debris previously in suspension at the surface of the land. Lateral filtration, especially through mats such as are present in swamps, is also an important process leading to the concentration of silt and of the fractional solid products arising from the maceration of organic bodies.

While the direct influence of filtration in assisting in the concentration of mineral substances of commercial value awaits detailed investigation, the suggestion is pertinent that in certain instances the retention at a given locality of surface precipitates, as, for example, bog iron ore, may be due in a determinable measure to lateral filtration through vegetable mats. Possibly, also, when chemical precipitates are formed in fissures or other openings in rocks, filtration in certain instances may be a part of the process of which the solid particles produced are prevented from becoming widely disseminated.

In studying the influence of filtration, it needs to be remembered that there is but an indefinite boundary between well characterized examples of the process and the influence of obstruction on more or less completely debris-charged air and water currents. The rushes growing in a stream

may cause sedimentation by checking the current or producing eddies, while a mat of sphagnum might lead to the complete classification of percolating water; but there is no definite boundary between the two agencies, so far as their physical action is concerned.

SEDIMENTATION

In the brief outline just given of the functions of air and water currents in promoting the concentration of either inorganic or organic debris, the selective process performed by gravity was made prominent. This same group of changes, visible in a different way, has in part been termed sedimentation. The operation of currents, however, is not strictly essential in the process of sedimentation, although under natural conditions almost always present, as an assorting of debris in suspension in still water, takes place. In still water, substances of less specific gravity than the water, whether fresh or saline, rise to the surface, thus indicating concentration, which, should currents be present, leads to still further concentration, as in the eddies of streams, in ocean currents, etcetera. Material of greater specific gravity than the water in which they are suspended descends under the pull of gravity and is assorted, in reference to the ratio of volume and weight. A like result follows when debris is suspended in still air and graded layers of dust and of dust-like particles result.

In the case of heterogeneous fragments in a minute state of subdivision, in suspension in water, other conditions, as the molecular attraction of particle by particle, the chemical nature of the substances in solution in the water, and their relative proportions, and yet other and still less well understood conditions, as, for example, in reference to electricity, become important functions. An illustration is furnished when streams deliver fine silt in suspension to the ocean and flocculation on account of the substances in solution in sea water occurs, which quickens the rate of sedimentation.

The importance to the geologist of the process of sedimentation in leading to the concentration of fractional parts of previously heterogeneous debris, whether inorganic or organic, is attested by the accumulations that are present on the floor of streams, lakes, and the ocean. The fact that like results have been attained throughout geological history is made evident by the extensive and frequently thick strata of shale, sandstone, limestone, etcetera, and by similar metamorphosed sediments in various geological terranes.

The importance to industry of the results of the processes of concentration just considered is illustrated by the manifold uses of stratified deposits of gravel, sand, and clay, by a large class of building stone, metals obtained from placer mines, and by many other accumulations.

MECHANICAL CONCENTRATION OF LIQUIDS AND GASES

In the above outline review of the various processes by which mechanical agencies lead to the concentration of various classes of products, only matter in the condition of a solid has been considered. The far-reaching principle involved, however, applies to the gathering together under certain conditions of liquids and gases. The extent and importance of this phase of the subject is illustrated not only by lakes, seas, the ocean, ground water, which require only mention at this time, but by certain more special or more exceptional occurrences, such as the accumulation of petroleum and rock gas in porous terranes beneath impervious and at times arched roofs, and in fissures, caverns, and other openings. The process of concentrating gases heavier than air at the earth's surface is exemplified by the accumulation of carbon dioxide in Death gulch, in the Yellowstone National Park, and many other similar instances elsewhere.

In the case of liquids and gases concentrated in these several ways, either at the earth's surface or in the outer portion of the lithosphere, it is a prerequisite that receiving reservoirs should be present, but in searching for the dominant principle which leads to the transfer of liquids and gases from one locality to another and their accumulation, particularly in commercial quantities, it is evident that gravitation plays the leading part.

SELECTIVE POWER OF GRAVITATION

In the various assorting processes controlled principally by gravity a selective power is exercised with reference to certain physical properties and the ignoring of other similar properties. For the most part, gravity takes note of the ratio of weight and volume, but in part makes a selection in reference to form, and again derives assistance from molecular attraction, and from electrical or other but little known or but imperfectly understood conditions.

In a negative way it may be said that mechanical processes of concentration take no account of chemical composition, crystalline or other structure, or of color, hardness, or elasticity, except so far as their properties affect size, weight, shape, or attraction or repulsion.

Mechanical concentration is in brief a physical process leading to the

accumulation of solids, liquids, and gases with certain like physical properties.

SPHERE OF INFLUENCE

The field of operation, so to speak, of the various processes which bring about mechanical concentration is essentially the earth's surface. Included in it are the lower portion of the atmosphere, with an indefinitely defined outer limit, the waters of the earth's surface, or what may be termed the free hydrosphere, and the outer film of the lithosphere. To some small extent the processes in question perform their functions in caves and fissures, but below a depth of a few score meters from the surface of the lithosphere the conditions on which their activities depend cease to exist. Former land surfaces and ancient lake and ocean beds, however, are now in many instances buried beneath subsequently formed aqueous or igneous terranes, and ancient mechanical concentrates are present far below the present surface of the earth.

Chemical Concentration

THE AGENCIES INVOLVED

The processes of concentration which are characteristically of a chemical nature result principally from solution and precipitation, but others, which are dominantly chemical changes, such as sublimation, crystallization, replacement, etcetera, play important roles.

SOLUTION

Concentration by solution results in two classes of products: First, residue or the fractional parts of substances acted on by solvents which remain when their more soluble associates are removed in solution, and, second, the material entering into solution which may or may not be more highly concentrated than during its previous state, but which in many and probably most instances is in a condition favoring later concentration, owing to precipitation or some other process.

The process of concentration by solution under natural conditions includes solvent action of gases, liquids, and solids; but for the present only the part taken by liquids, and still more strictly, only the action of water, will be considered. No change known to have occurred in the material composing the earth is, perhaps, more important or carries with it such far-reaching geological results as the familiar process of solution. The underlying principle is that a selective action is brought into play, since the solubility of various substances, as it seems, has as wide a range

as do the combined physical and chemical properties of all the substances entering into the composition of the earth.

RESIDUAL CONCENTRATES

Owing to the selective power of water, the universal solvent, certain substances under prescribed conditions, especially of temperature and pressure, are taken into solution and carried away, leaving in many instances other substances as a residue. The world-wide importance of this process is forcibly shown by the abundance throughout many extensive regions of residual earth. The familiar *terra rossa,* consisting essentially of iron-stained clay, no matter what may have been the nature of the rock from which it was derived, is evidence that the process of selective solution carried on by percolating water aided by organic acids is a most important agency leading to the disintegration of the rocks forming the superficial film of the lithosphere and the concentration of a part of the resultant debris.

The principle illustrated by the mode of origin of *terra rossa* applies to many other substances, some of them of great industrial value. Among the numerous examples that might be selected, none, perhaps, will serve better than the so-called fossil iron ore of the Clinton formation in the Appalachian region, which in certain important instances, if not in all cases, has resulted from the leaching of ferruginous limestone; the more soluble constituents of the rock having been removed in solution, leaving the less soluble ferric oxide as a residual concentrate. Again, in the lead and zinc mining districts of the Mississippi valley and the silver and gold fields of the Pacific mountains and elsewhere, natural concentration produced by the removal of the more soluble constituents from mineralized rocks, mineral veins, etcetera, has led to the concentrating of residual minerals and ores of great commercial value.

Knowing the process by which residual concentrates are produced and the nature of the material from which they are derived, guides are furnished which aid in the search for rock residuums. Important principles in this connection are: The process goes on most actively where rain is abundant, the temperature high, and plant life luxuriant. Each of these dominant conditions, as a further analysis would reveal, is dependent on other conditions, which we denominate as secondary, none of which could be eliminated without seriously impairing the results, any more than the smaller wheels or cogs in a watch could be removed without stopping the action of the mainspring or other, as they seem, more essential portions of the mechanism. Geographically, the process of residual concentration through the action of chemical agents is at its

maximum degree of efficiency in warm, humid regions, and diminishes when toward the region of less mean annual temperature or of summer warmth and toward regions of little or no rainfall. A like graduation, but dependent on variation in temperature and humidity, is also present from densely plant-clothed areas to either hot or cold deserts.

Concurrently with the production of residual concentrates as with all other products of concentration, in order that important accumulations may result, is the fact that concentration must progress at a greater rate than the process of removal or redistribution. The fact that under given conditions material of a particular kind is concentrated carries with it the conclusion that at the same or other localities depletion is in progress; concentrates in general represent the net result or algebraic sum of the results of agencies tending to bring like kinds of matter together in a given locality over the results of the same or other agencies tending to dissipate or redistribute material.

Residual concentrates, therefore, in order to be extensive or commercially important, can only occur in regions where they are to a conspicuous degree shielded from, or are beyond the reach of, destroying or diminishing agencies. Of the agencies which remove surface material, streams and glaciers are the most important. As the production of residual concentrates goes on most actively in regions of abundant precipitation, they are especially liable to removal through the denuding operations of streams, but derive protection from the vegetation usually present in such localities. In going from regions of heavy precipitation to regions of little or no rain, rock decay diminishes, but the efficiency of the rain wash and streams in promoting denudation also diminishes, on account of diminution in the amount of water available to do the work, although other factors, as decrease in density of vegetation, also enter into the problem. Although the conditions are highly complex, the result of observation seems to be that in warm, humid regions rock decay, and consequently the concentration of residual material, is most apt to be in excess of depletion, owing to the denuding action of streams. It is in such regions that the prospector looks for the most extensive residual concentrates, although even at present the most arid regions hold out promises of rich rewards.

Of the agencies tending to remove residual concentrates, glaciers work most thoroughly and most efficiently. So generally is this fact known that no well informed prospector would expect to find commercially valuable surface concentrates in regions scoured by glaciers during geologically recent times.

The habitat, so to speak, of residual mineral and rock fragments, which are left when the more soluble associated material of the original rocks is removed, is the surface portion of land areas to the depth of the zone of weathering. Below the surface of saturation, or the water table, solution and deposition are active processes, but the former is far less prominent than the latter, and leached mineral or rock masses are not prominent. As is familiar to miners the world over, residual and oxidized minerals and ores are limited in depth by the upper surface of the zone of saturation, and below that horizon deposition resulting in concentration and not depletion is the rule. The search for residual concentrates is thus limited by a definite and easily determinable horizon, unless a recent or comparatively recent rise of the level of ground water has occurred.

SURFACE AND SUBSURFACE PRECIPITATES

The substances taken into solution by percolating water in the zone of weathering present great variety. In fact, all known chemical elements are present in greater or less abundance in surface and subsurface water. The zone of weathering may truthfully be said to be a vast laboratory in which the concentration of mineral matter is brought about not only on account of chemical inertia at the temperatures present, as in the production of residual concentrates, but a great variety of chemical precipitates also result and furnish examples of concentrated material frequently of great commercial importance.

EVAPORATION

The concentration of mineral matter other than residual material, at the earth's surface and in the zone of weathering, through the dominant agency of chemical processes results principally from evaporation, decrease in temperature, and chemical reactions.

Evaporation leads to the precipitation of mineral matter from water solutions to some extent while the water is in the zone of weathering, but principally from surface water, in part returned to the surface after short subterranean journeys, as from the surface of the land and from streams, lakes, seas, and the ocean. Resulting from this process, which is coextensive with the earth's surface, many and important chemical concentrates are produced. As a rule, the substances laid aside in this manner, in more or less well defined accumulations, are such as are readily soluble, but are present in such abundance that evaporation quickly produces a state of saturation, as, for example, in the case of calcium carbonate, sodium chloride, and sodium sulphate.

Water in the zone of weathering is either under the dominant control of gravity, as when it occurs in fissures, caverns, etcetera, or occupies the interspaces between the pebbles or grains of gravel or sand and moves in response to the pull of gravity exerted directly or indirectly under the form of hydraulic pressure, or adheres to the solids present and is held by them as surface films, owing to molecular attraction. In general and as it appears universally, the free water content of cellular and porous rocks is not saturated with any of the substances it contains in solution, and evaporation does not lead to precipitation. When, however, the free water percolates away, leaving only films of water adhering to the surfaces of the solids present, evaporation is favored and all the mineral matter contained in the water films is frequently precipitated. This process of subsurface evaporation goes on most actively adjacent to the surface of land areas and decreases essentially in arithmetic ratio with increase in depth. It is most active in open textured rocks, like beds of boulders and pebbles, and decreases inversely with diminution in the cellular condition of the containing terranes. By this process precipitates are formed which incrust the surface of the solids present, and in the case of terranes composed of sand grains, pebbles, etcetera, in many instances increases in volume until the fragments are cemented and under favorable conditions the interspaces are completely filled.

The process of subsurface concentration just outlined is modified in a conspicuous manner by climatic conditions, and especially by the degree of humidity and temperature. Its results are most conspicuous in regions of small rainfall and of high temperature, and especially where periodic or occasional rains occur in regions of high mean annual or seasonable temperature, and are less common in cold, humid regions. Examples of the growth of this process are furnished by the cemented subsurface crusts or alkaline hard-pans of arid regions and by the lime cemented gravels occurring near the surface in humid regions.

A delicate adjustment between the conditions favoring subsurface concentration by evaporation and the removal of the precipitates formed in solution is frequently manifest by the deposits in question. In regions of small rainfall the precipitates which may be termed perennial contain such readily soluble substances as sodium sulphate and carbonate and calcium sulphate, but in more humid regions, where the volume of percolating water is greater, such salts are usually eliminated and the more abundant calcium carbonate alone remains. A still more delicate adjustment of the same nature is frequently illustrated in humid regions, where in many instances incrustations of calcium carbonate occur principally or wholly on the under surfaces of the pebbles and stones in

gravel deposits, it being in such situation that the solvent action of percolating water is least and where, also, the conditions favoring precipitation from slowly percolating water are more favorable.

The process of subsurface concentration of mineral matter, owing to evaporation, leads to the hardening of rock outcrops, the production of efflorescence, gypsum rosettes, similar incrustations in caverns, and is a factor favoring the growth of stalactites and stalagmites.

The process of concentrating readily soluble minerals, owing to the evaporation of water from the surface of the land, is illustrated by the efflorescence which forms in desert regions, where, owing to the drying of porous material, water is drawn from below the surface by capillary action and the mineral matter it holds in solution is precipitated as the water evaporates. This snow, as it appears when viewed from a distance, of hot arid lands, frequently contains sodium chloride, sulphate and carbonate, as well as boracic acid, calcium, etcetera, and is at times of commercial value.

The rise and outflow of previously subsurface water from springs leads to important changes in the conditions exerting an influence on the solvent power of the emerging waters which favor concentration of mineral matter in a variety of ways. Decrease of pressure, freedom of escape for dissolved gases, decrease in temperature of water which comes from a considerable or great depth, and a rise in temperature from the water of hillside springs (the latter favoring the precipitation of calcium carbonate), exposure to the air thus preventing oxidation, and most of all the emergence of the water into the light, thus favoring in a high degree the growth of living organisms, and particularly of algæ, lead to the formation of abundant concentrates, the most common of which are calcium carbonate, silica, gypsum, iron oxide, inorganic acids, etcetera. In this complex process evaporation is an important factor, particularly in the precipitation of silica by hot springs and geysers.

During the transit of surface water supplied in part by springs and seepage to inclosed lakes and the ocean, concentration by evaporation continues, although precipitates from this cause in streams seem seldom, if ever, to be found.

The waters of streams on reaching inclosed lakes or inland seas evaporate and the mineral matter they contain is concentrated. Frequently, as is well known, this process leads to precipitation and the formation of deposits of calcium carbonate and calcium sulphate. A similar process operates in lagoons shut off from the ocean, and the ocean itself is a vast evaporating jar in which brine is concentrated both locally and under

exceptional conditions, and the point of concentration and deposition for any of the substances present in solution.

In the process just outlined, concentration by evaporation is the leading control, but chemical reactions, life, and variation in temperature, escape of gases which enhance the solvent power of water, and other conditions exert important influences.

Of the secondary conditions, variation in temperature has received less attention than perhaps any of the other modifying conditions enumerated, but its importace is indicated on a grand scale by the precipitation of sodium sulphate from the waters of Great Salt lake during the prevalence of abnormally cold seasons.

The escape of gases from water when pressure is relieved, as in the case of springs which have their sources deep in the earth, or when greater surface of exposure to the air is brought about, as in water percolating into caverns, is also an important and at times a controlling factor leading to precipitation. The best known illustration of this process is the escape of carbon dioxide, which when present in water gives it enhanced power to hold calcium bicarbonate in solution. The critical study of this process from a geological point of view, and concerning other gases in addition to carbon dioxide, remains to be undertaken, but gives promise of furnishing instructive information.

The results of concentration by evaporation fall into two groups, each of which may be of commercial value. Solids are precipitated from solutions which themselves remain as liquid concentrates or mother liquors, and while yet in the open evaporating pans in which they were produced are n some instances of economic importance as well as of scientific interest. A place is thus provided in our general scheme of classification of natural concentrates for the brines of dead seas and buried saline waters, in some instances rich in bromides, iodine, etcetera, as well as rock-salt, gypsum, anhydrite, and for saline deposits of varied character, such as are mined at Stassfurt. The geographic distribution of the solid and liquid products of concentration resulting from evaporation while still present at the surface of the earth is controlled mainly by the distribution of solar heat and of precipitation. The conditions favoring this production and preservation increase from locality to locality with increase in mean annual temperature and with decrease in precipitation, providing the requisite conditions of relief of surface, such as the pressure of inclosed basins, are present. With a knowledge of the climatic conditions essential to the production of concentrates by evaporation and of the nature of the receptacles required, a means is furnished for determining the conditions under which buried fossil salts and brines of similar char-

acter were produced. In this manner ancient concentrates serve a purpose analogous to that supplied by plant and animal fossils in determining the nature of former climatic oscillations. In attempting to apply this principle, however, it should be remembered that during early geological eras the earth's interior heat may have played the role now assigned to solar heat, and also that throughout the time embraced in geological history the residual heat of lava beds may have produced similar results.

Of the concentrates resulting mainly from evaporation at the earth's surface as in the zone of weathering, the next class in order of abundance after the brines and salts contains the products resulting from the evaporation of petroleum.

Petroleum, when occurring in quantities of commercial importance, is, as previously stated, a result of mechanical concentration, but when evaporated under natural conditions yields gases, semi-solids, and solids. The gases may be widely diffused in rocks as in the air, or concentrated, according to the presence or absence of collecting or storage reservoirs. The residues, either in a liquid or solid condition, left by the evaporation of the more volatile portions of the original fluid, remain in the cavities and fissures of greater or less size, or more or less completely saturate porous rocks in the superficial portion of the earth's crust, or are produced at the surface. The residues resulting from the evaporation of petroleum constitute the naphthas, mineral tar, asphaltum, ozokerite, grahamite, albertite, etcetera.

In this connection, again, a knowledge of the mode of concentration by which fractional parts of previously more complex or more heterogeneous material are segregated, aided by a knowledge of the nature and kinds of receptacles necessary for the storage and preservation of the concentrates produced, is an aid in the search for commercially valuable deposits of the nature just considered.

SUBLIMATION

Analogous to the process of evaporation is the process of sublimation, whereby matter is changed from a solid to a vaporous condition without alteration in composition and redeposited as a solid when the temperature is sufficiently lowered. The process of sublimation as commonly recognized, and so far as its geological action is concerned, requires a high temperature in reference to the sun-derived heat of the earth's surface, the source of which is the earth's interior. The heat is transferred to the earth's surface as a part of the functions of volcanoes, and the substances sublimed may be considered as by-products of volcanic activity.

The most common geological deposits which owe their concentration to the process under consideration (not at present considering water as a part of the category or attempting to strictly define sublimation as a physical-chemical process) are sulphur, arsenic, mercury, etcetera. Owing to the high temperatures present in volcanoes, inclusive of their funnels and solfatara stages, and the variety of substances usually present, the chemical activity is conspicuous, and it is difficult to differentiate the concentrates resulting from sublimation simply from the results produced by chemical reactions, evaporation, etcetera. For the present at least it seems best from a geological point of view to make a special class of the concentrates resulting from the direct action of the earth's internal heat, when transposed to the earth's surface, and term these fumarolic and solfataric products. The concentrates of this class produced essentially in the absence of water, except in the condition of steam, are analogous to hot-spring deposits, in the production of which the earth's internal heat is the dominant agency, in association with water. In fact, the concentrates formed in connection with fumaroles and solfataras may be considered as the products of hot-gas springs. In a manner similar to the way in which the deposits from hot-water springs grade into other forms of aqueous deposition, so the fumarolic deposits merge with other accumulations resulting from the action of volcanic heat at the surface or in the rocks through which the conduits of volcanoes pass.

Another phase of volcanic activity, which, however, can at present be considered but briefly, is the concentration of gases arising from the disassociation of the elements of substance exposed to the high temperatures prevailing in volcanic vents. By this process various gases result, as, for example, hydrogen, oxygen, nitrogen, ammonia, etcetera, and various acids in a gaseous condition; but in general and perhaps always, so far as the geologist is especially concerned, these concentrates, owing to their great chemical activity, and also, as a nearly universal rule, the absence of suitable reservoirs in which they can accumulate and be permanently stored, do not demand attention as geological deposits.

CHEMICAL REACTION RESULTING IN PRECIPITATION

A highly varied group of natural chemical concentrates have as the principal or controlling agency leading to their production what is termed chemical reaction, or the mutual disassociation of the elements in two or more compounds when brought into intimate relations with one another under certain conditions of temperature, pressure, etcetera, and the production of one or more new compounds which may separate out and be placed by themselves. For example, if a water solution contain-

ing ferric carbonate is exposed to the air, the iron at normal surface temperatures and pressures will exchange its carbon dioxide for oxygen and be precipitated as ferric oxide. In other words, there is the process in nature whereby chemical precipitation leads to the concentration of ferric oxide.

The example cited above, of the precipitation of ferric oxide, is a chemical process, normal, as one may say, to the established order of physical conditions of the outer earth. Hence, together with other similar or analogous instances in which the bringing of bodies or volumes of material into intermediate association leads to the precipitation or segregation of one form of matter apart from other forms, it may be termed concentration owing to chemical reactions.

In an extension of our classification indicating methods of concentration the subdivisions of the results of chemical precipitation may be based on the nature of the products or on the processes included in this concentration. Suggestive categories may be formed by each of these methods, but for our present purpose and for the sake of economizing space subdivisions based on the major features of the processes involved are here considered.

Chemical reactions resulting in the concentration and preservation of various forms of mineral matter take place in nature in the main by the (1) union of gases with gases, (2) the union of liquids with liquids; and here we include the union of substances or ions in solution (3) by the union of gases with liquids or solids and by the union of liquids with gases or solids. The significant result of these various unions, so far as the present discussion is concerned, is that solids of specific composition are produced which may be reckoned as geological concentrates.

1. The interaction of gases with gases in nature causes the precipitation of such substances as ammonium chloride, borates of the alkaline earths, sodium carbonate, ferric chloride, and a variety of other products, some of which are of commercial importance. These substances when deposited in and about volcanic conduits, as already stated, are commonly associated with the products of sublimation, and the two classes have been tentatively classed as fumarolic concentrates.

2. The reactions between substances in solution, or, as is perhaps a more accurate statement, the affinity between different ions when substances are in solution, is the fundamental factor in chemical concentration. Principally, however, at or near the earth's surface, chemical unions which lead to the precipitation of solids from solutions are controlled in a conspicuous manner by temperature changes, evaporation, relief of pressure, escape of gases from solutions, vital processes, etcetera,

certain results of which have already been cited and others will receive attention later. After recognizing the results of these various processes, there remain certain precipitates that result from the commingling of waters with different chemical constitutions, which may be termed concentrates due to chemical reactions.

The surface waters of the earth are dilute chemical solutions, and by their mingling, as when two streams join, springs are tributary to lakes, etcetera, no recognizable precipitates are formed. In inland lakes and the ocean, direct chemical precipitation not dominated by concentration, by evaporation, by vital action, or other processes recognized in our schedule are of such minor importance that no characteristic examples seem recognizable. In the laboratory of the outer film of the lithosphere, or the zone of weathering through which weak chemical solutions are passing, but linger for shorter periods than is the case at the surface above or the zone of cementation below, precipitation on account of chemical reactions is in general of minor importance. Such substances as certain salts of iron, copper, zinc, etcetera, and silica and a few silicates, etcetera, which are formed are closely associated with the residues left from solutions and in general may be classed with them. In the portion of the lithosphere below the zone of weathering, as will be noted later, chemical reactions under the influence of energetic physical conditions become of paramount importance.

3. The union of liquids, or, more precisely, of water with solids, finds its chief field of activity in the zone of weathering, and is illustrated by the hydration of certain minerals, as, for example, the change of anhydrite to gypsum and the alteration that certain of the feldspars experience. Relief of pressure accompanied by the pressure of water, which rocks experience when they pass into the zone of weathering, owing to the removal of previous incumbent terranes, seems to be the leading factor in this change. Although hydration is of importance in the study of the disintegration of rocks and is an agency in preparing material for mechanical concentration, as a direct process leading to the transfer of material from one place to another which is in more or less complete isolation—that is, as true concentration—it does not seem to play an important role.

Physical-chemical Concentration

The zone of weathering has been likened to a chemical laboratory in which great results are produced. The operations carried on in it, however, are such as require for the most part low and nearly uniform temperatures and correspondingly small and nearly constant pressures. The

exceptions are in association with the outward migration of heated waters or of magmas from deep within the earth. It is in the inner earth from which the igneous rocks now at the surface have migrated that the earth's great physical-chemical laboratory is located and those geological processes requiring high temperatures and great pressure are carried on. In the lithosphere below the zone of weathering two important divisions in reference to the processes of concentration may be recognized—an outer zone, in which water may exist in cavities and also because the temperature is not sufficiently high to reach the critical temperature above which the elements of water are disassociated, and an inner zone, or the earth's centrosphere, in which these conditions are reversed.

The zone beneath the zone of weathering is a zone of saturation, whose waters linger or in general migrate but slowly, and where also temperatures are high and pressure enormous and progressively increasing with depth. Under these conditions the chemical reactions are favored and the results, so far as concentration of mineral matter is concerned, are free from the complications that arise when evaporation, sublimation, and influences of life are active. This zone is thus especially favorable for the production of mineral concentrates through the process of chemical reaction, as has already been emphasized by Van Hise, who has named it the zone of cementation. In the zone of cementation cool descending waters meet and commingle with heated ascending waters, and lateral migration of solutions involving changes of temperatures and pressure also occur. The fact that in this zone, which is in a condition of saturation, the water present is under pressure and subject to the laws of hydrodynamics, and in consequence will move from regions of greater to regions of less pressure, irrespective of direction, is sometimes lost sight of. Possibly also in the case of highly heated and saturated rocks the principal governing the diffusion of solutions through membranes or endosmosis may play a part in the migration of matter.

Under the general conditions named—that is, high temperature, saturation, slow movement of water, and hence abundant time for chemical processes to act and great pressure—the one thing that controls concentration is the presence of suitable receptacles in which the materials precipitated may be accumulated and preserved. Such receptacles, as is attested by mineral veins, are furnished by cavities in the rocks. When the cavities are small and in general evenly distributed, we term the process of concentration of mineral matter cementation. When the cavities are larger and cave-like in character, geodes and agates result. When the cavities are produced by fracture and open fissures result,

their filling results in the formation of fissure veins. In case solution furnishes the requisite receptacle, which in general, as it seems, becomes filled as rapidly as formed, concentration by replacement results.

The great group of concentrates just referred to results from chemical precipitation under the direct and immediate control of physical conditions, chief among which are variations in temperature and pressure. So complex are the conditions leading to the filling of cavities in the zone of cementation and so little are they understood that it does not seem practicable to classify the results in terms of the agencies in operation. In order to make convenient subdivisions among the results produced, resort must seemingly be had to the character of the receptacles in which concentrates have been placed, as has been done in classifying mineral veins, geodes, agates, amygdules, etcetera, or else the mineral composition of the concentrates themselves employed for a like purpose and various ores and mineral deposits recognized. As is well known, each of these methods has been employed, but without formulation of a definite system of classification.

In the zone of cementation, as has been mentioned, the temperature is normally below the critical temperature for water. A higher temperature, especially if the fusion of rock results, leads in general to the diffusion and not to the concentration of mineral matter. Under certain conditions, however, when heterogeneous material is in a fused condition, or when part of a magma crystallizes, leaving other portions still liquid, gravitation may lead to the separation of lighter from heavier magmas, or to the settling of solid products from a cooling magma, or from one in which decrease of pressure has favored partial crystallization. These two processes, although distinct, depend on selective gravitation and may progress at the same time. The nature of the magmas composing the earth's highly heated interior is known in part from the study of the extrusions of plastic or liquid rock discharged by volcanoes, but in general it is only the cooled and crystallized material which was present in the earth's centrosphere and has been forced outward that is available for examination.

The study of igneous rocks has shown that concentration during the process of cooling has resulted in the formation of minerals, but in general these are not gathered into groups or masses, but disseminated through the rock. The layers of the disseminated concentrates are crystals of various minerals, and the ones of commercial value are principally feldspar and certain gems. In certain instances, however, as in the case of pegmatite veins, original concentration from a magma seems to have occurred; but even in these instances later concentration

through the agency of highly heated percolating water seems to have followed. In fact, it seems inadvisable at present to attempt to draw a dividing line between the results of crystallization and segregation of minerals directly from magmas and subsequent concentration, owing to the action of percolating heated water while the mass was slowly cooling. These two processes must grade one into the other and their results merge in a complete manner.

Magnetic segregation, during which the heavier minerals crystallizing out of a magma migrate toward the bottom of the mass and lighter minerals toward its summit, or outer portion, appears to be a fundamental principle which should lead to the production of definite concentration. Examples of this method appear to be furnished at the Sudbury district, Canada, as described by Colman.

Vital Concentration

THE AGENCIES INVOLVED

In attempting to briefly review the various ways in which living organisms lead to the concentration of mineral matter, two divisions should be made—one to include what may be termed the geological work of plants, and the other to embrace the similar functions performed by animals. Under each of these divisions the composition of the substances segregated suggest subordinate headings. For the sake of economizing space, however, only certain typical examples will be cited.

The principal substances of geological importance segregated by plants and animals as a part of their vital functions are carbon, silica, and calcium carbonate; but a more extended analysis would include potash, soda, magnesia, sulphur, iodine, etcetera.

CARBON

In the whole range of selective functions, either inorganic or organic, under review, perhaps no better illustration is furnished of the principle made prominent in this address than by the manner in which land plants decompose the carbon dioxide of the air and fix the carbon in their tissues. This process of obtaining carbon from an invisible gaseous source and giving it a solid form is the mainspring of a great series of geological as well as of industrial results. The processes by which peat beds and other accumulations of carbon are produced are too well known to be discussed in detail at this time. An important auxiliary principle of wide application, of necessity operating in conjunction with the principle of concentration, however, is perhaps best illustrated by

the deposit of carbon in question—that is, the fact that accumulations of material must be present or their conservation insured for, in general, a great length of time in order to be of geological or economic importance. Methods of preservation thus become only secondary in importance to the methods of primary concentration. In the case of carbon, accumulations are made; this concentration is promoted in several ways, prominent among which is submergence in water, which, as a part of the process, is rendered to a conspicuous degree antiseptic by reason of certain products of organic origin, as is well known in the case of the amber-colored water of swamps; still longer preservation is involved when peat-bog, drift timber, etcetera, become buried beneath sediment or other deposits, which serve to compress it as well as exclude the ravenous oxygen. Another important method of preservation, and one to which but little heed has been given, is illustrated in the vast tundras of another latitude, where vegetable matter comparable in volume with that of our largest coal fields has it decay arrested by low temperature. The incipient coal beds of the tundra marshes owe their preservation literally to a process of cold storage. In the review that is evidently demanded of the glacial records of approximately Permian age in various parts of the world, the suggestion that some of the late Paleozoic coal beds are of tundra origin may, perhaps, make certain facts significant which would otherwise be passed by with scant attention.

CALCIUM CARBONATE

The methods of concentration through the action of plants, of calcium in combination with carbon dioxide, recently so clearly demonstrated by Weed in reference to hot-spring deposits, and by Davis concerning the so-called marl of freshwater lakes, are of fundamental importance to geologists. If such striking results are now produced by this method of concentration, our cherished faith in uniformatism should certainly lead us to scan the history of past times with the hope of learning when this function began to be exercised and what part it has played in recording geological events. The question is pertinent. Do the more or less local and frequent lenticular beds of limestone in certain formations now partly crystalline schists, represent the products of concentration brought about by algæ?

Other and more familiar methods by which the concentration of calcium carbonate is brought about need only be mentioned to indicate the important place they hold in the scheme of classification of the widely extended operations of nature under review, which in truth have made the earth habitable by living creatures. The hard parts of foraminifera,

corals, crinoids, mollusks, etcetera, as is well known, form terranes which in the aggregate measure thousands of cubic miles. The geological and industrial importance of these organic accumulations and the clearness with which they demonstrate the continuous action of life in segregating mineral matter throughout the zoic division of geological time speak eloquently in favor of the definite recognition of the principle of concentration as a geological process.

SILICA

What has been said relative to the concentration of calcium carbonate might be said again concerning silica, with but little change in the wording. The diatoms among plants and radiolaria and sponges, especially among animals, have throughout eons of time been forming stones for the geological temple, and through the solution and reconcentration of the material secreted have furnished a cement for other stones in the structure.

The importance of the principle of concentration concerning the resultant or by-products of the vital functions of plants and animals might be illustrated at greater length, and the conditions leading to the accumulation of deposits of iron, phosphorus, sulphur, and many other substances, dwelt upon, but enough has perhaps been said to show the importance of the subject.

Summary

Attention has been invited to the broader phases of the processes active in nature which lead to the concentration of mineral matter. A classification of the processes referred to has been suggested, the primary divisions of which take cognizance of the dominant form of energy, whether mechanical, chemical, physical-chemical, or vital, which in certain large groups of the changes considered exert the major control. Subdivisions of these primary classes, based on determining or qualifying conditions and on selective or transposing agencies, have also been introduced, as it is thought they will be of service to the geologist. The scheme is intended to be sufficiently elastic to admit of the interpolation of as yet unrecognized determining or qualifying conditions or agencies and of a minute classification of products or results.

As an attempt has been made to show, the field of operation of the principles presented is as extensive as the earth, and embraces not only its surface, but its interior, and is as far reaching as geological time. Although an underlying principle has been dwelt upon and emphasized,

it is not to be understood that it stands alone or is the sole guide which a geologist should follow in reaching for materials of industrial importance. Concentration in one way or another has filled nature's storehouses, but the origin of the receptacles, their size, association, the conditions favoring their preservation, etcetera, are important matters to be considered. The very activities which lead to storage necessitate as a part of their functions depletion in many instances of previous accumulations. As in so many other geological processes, destructional and constructional action are involved in the various processes of concentration, and the result is in many instances the algebraic sum of the two. In dwelling on the process which favors accumulation, the concurrent activities favoring dissipation need to be borne in mind and at some other season given a place of prominence.

In Conclusion

From the sands at our feet I have selected a pebble and held it to the light. It is perhaps not a flawless crystal, but can with greater truth be termed bort, which may be put to industrial uses instead of treasured on account of its beauty or rarity. The pebble, as I have identified it, is a true and broadly underlying principle, which is worthy of recognition, which should be given a place by geologists, and especially in books dealing with the application of our science to commercial industries. By understanding the methods by which storehouses of the earth have been filled, the seeker for hidden treasures will be better able to locate his claims.

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CARBONIFEROUS OF THE APPALACHIAN BASIN *

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(*Presented by title before the Society, December 29, 1906*)

CONTENTS

* The earlier papers of this series, now closed, are in this Bulletin, volume 14, pages 15-96; volume 15, pages 37-210; volume 17, pages 65-228. The writer desires to acknowledge his obligations to Doctor I. C. White and Mr David White, who throughout the whole period of his study have been unreserved in giving information and criticism. At the same time it must be understood that these observers are committed in no wise to conclusions offered by the writer.

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The Monongahela Formation

CORRELATION

The practically continuous area of Monongahela is confined to the southwest four counties of Pennsylvania, a narrow strip in eastern Ohio, and central West Virginia. Small outlying patches remain east from the Alleghenies, in the First and Second basins of Pennsylvania, and, at the south, beyond the Kanawha river in West Virginia. The area in which this formation remains is far within that of the Conemaugh, except at the east.

The formation, as limited by Doctor I. C. White, has the Pittsburg coal bed as the lowest and the Waynesburg coal bed as the highest stratum. The thickness varies from somewhat more than 400 feet in central West Virginia to about 140 feet at the most northerly exposure in Jefferson county of Ohio. This formation is characterized by notable variation in thickness of intervals and in composition of the rocks, as well as by local irregularities of deposit, whereby every student in the several parts of the area has been led into serious errors of correlation. These have made study of the Monongahela more perplexing than that of any earlier Carboniferous formation.

In ascending order, the important members of the formation are:

Pittsburg coal bed.
Pittsburg sandstone.
Redstone limestone.
Redstone coal bed.
Fishpot limestone.
Lower Sewickley coal bed.
Sewickley sandstone.
Upper Sewickley coal bed.
Benwood limestone.
Tyler red beds.
Ritchie red beds.
Uniontown limestone.
Uniontown coal bed.
Uniontown sandstone.
Waynesburg limestone.
Little Waynesburg coal bed.
Waynesburg coal bed.

The Pittsburg coal bed........Maryland: Cumberland, Elkgarden, Great vein, Pittsburg. Pennsylvania: Pittsburg, Connellsville, I. Ohio: Federal creek, Pomeroy, Lower Barnesville, VIII, Pittsburg. West Virginia: Pittsburg.
H. D. Rogers, 1839.

At one time this bed was thought to be a practically continuous sheet underlying the whole remaining area of Monongahela, somewhat less than 20,000 square miles; but studies by Professor E. B. Andrews during the Second Geological Survey of Ohio proved its absence from a considerable part of the field in that state and Doctor White's study of oil well records in West Virginia, almost 20 years later, led to a similar conclusion for much of that state. The northern boundary of this barren area is in Guernsey county of Ohio and the coal is to all intents wanting in Noble, Monroe, east Morgan, and most of Washington in Ohio, most of Wetzel, Tyler, Pleasants, Wood, Ritchie, Doddridge, Gilmer, Roane, Calhoun, Jackson, Clay, Kanawha, Putnam, and Mason counties of West Virginia, all within the area in which formerly the bed was supposed to exist. Yet, even when thus restricted, the coal underlies a vast area, 7,000 or 8,000 square miles, in which it exhibits for the most part such regularity in variation as to both quantity and quality as to render it, from an economic point of view, the most important member of the formation and probably of the whole bituminous coal measures. Within the barren area itself it is represented frequently by black shale and occasionally it reappears abruptly as a bed of workable thickness.

The Pittsburg coal bed in the ordinary condition, as seen in most of Pennsylvania and Ohio, is double, showing a "roof" division separated by an "over-clay" from the "Main" coal below. The "roof," varying in thickness from a few inches to 10 or 12 feet, is composed sometimes of laminations of coal and clay; at others, the coal and clay are segregated into beds, each 6 inches to a foot, while again it is almost wholly coal or almost wholly carbonaceous shale. At the best the coal is inferior and is not mined. This division is wanting in the Salisbury basin of Somerset county, Pennsylvania, and is seen rarely along the eastern outcrop in West Virginia; but it reappears suddenly on the Kanawha, where at one locality it attains to almost the extreme thickness.

The "over-clay," varying from a few inches to 2 feet, is thoroughly persistent, though sometimes so carbonaceous as to be almost a bony coal; even in West Virginia it seems to be present always, though the "roof" is wanting.

The "Main" coal may be regarded as in three benches—"Breast," "Bearing-in," and "Bottom"—but in a great part of the field the "Breast" as well as the "Bottom" is divided by a thin parting, so that five benches are distinct. The parting slates are ordinarily very thin, rarely exceeding half an inch, often much less, and in considerable areas

some of them contain much mineral charcoal. The persistence of these filmy layers throughout thousands of square miles is not the least remarkable feature of this bed. The "Bearing-in," known in some localities as the "Bands," is not persistent in West Virginia, where along the eastern outcrop the bed is often only double, with a mere parting, there being no deposit between the benches. The coal is not the same throughout the bed, and each bench is apt to show its own type, distinguishing it as sharply from the others as though the partings were many feet thick. The coal differs in volatile, in ash, in coking qualities, and in sulphur; that from one bench is "brick;" from another, prismatic; from a third, hard, with more or less of semicannel. Like other beds, the Pittsburg occasionally carries some cannel; but this is unusual, occurring only on the border of the field.

The proportion of volatile shows variation geographically, as was indicated long ago by Professor H. D. Rogers. Along a line passing westnorthwest from Maryland to Ohio, the ratios between volatile and fixed carbon in the several basins are:

Maryland	4.47 to 4.78
Salisbury	3.18 to 3.38
Connellsville	1.81 to 2.07
Lisbon	1.38 to 1.83
Washington county	1.03 to 1.79

These ratios are taken from Mr A. S. McCreath's analyses. This decrease is most marked along the westnorthwest line, but there is in a general way a decrease northwardly in several of the basins. The volatile is high throughout Ohio. In West Virginia, as shown by Professor Hite's analyses, the volatile increases, there being as much in the continuation of the Connellsville as in the southern Lisbon of Pennsylvania; still farther south, on the line of the Salisbury basin, the ratio is 1.4, while in Mason County, on the central line of the trough the ratio varies from 1.04 to 1.33.

The Pittsburg coal bed has its greatest thickness at the southeast, in the Potomac areas of Maryland and West Virginia, where the Main coal is 12 to 14 feet. Along a westnorthwest line in Pennsylvania the thickness decreases, becoming 8 to 10 feet in the Salisbury, 8 to 9 in the Connellsville, 7 to 8 in the Lisbon, 6 to 7 in the Waynesburg, and 5 to 6 in basins farther west. It retains the latter thickness into Ohio, but more frequently approaching the lower figure. On the western outcrop, in Belmont and Guernsey counties of Ohio, the thickness falls to 4 feet, and at last to 3 feet 6 inches, the several divisions of the bed being still distinct. North from this line the bed grows thinner, slowly in the

Ligonier, Connellsville, and Lisbon, in which it retains a good thickness to the last exposure, but farther west the diminution is more marked, for in northern Allegheny the bed rarely exceeds 4 feet 6 inches, while in Beaver county it falls to 3 feet 6 inches; but in Jefferson of Ohio it is 4 feet at the most northerly exposure. The conditions along the northwestern and western outcrop are suggestive. The greater thickness in Jefferson and the marked increase to 6 feet southwest in Harrison county makes the greatly increased thickness, 8 to 9 feet, in western Morgan and Athens not at all surprising. It is clear that the thin coal of Guernsey is only evidence of approach toward the barren area, which begins in the southern part of that county. The western limit of the bed must have been considerably west from the present outcrop in Harrison, Guernsey, and Muskingum; it is probable that a great area of thick coal has been removed, and that the thick coal of Morgan at one time covered most of Muskingum and Carroll counties, west from Guernsey and Harrison. The great thickness at the extreme northern exposures within the Ligonier, Connellsville, and Lisbon basins leads to the belief that Professor J. P. Lesley was not far wrong when he suggested that the Pittsburg at one time reached almost to lake Erie.

While the bed loses thickness from all sides toward the central area, where it is wanting or so insignificant as to be unimportant, it is equally true, as already stated, that even within that area one finds patches in which the bed is of commercial importance. One of them, with Pomeroy, Ohio, as its chief shipping point, has an area of not far from 100 square miles; those along the Kanawha in West Virginia are smaller, but there the bed shows at times its complex "roof," "over-clay" and "Main" coal, with the latter exhibiting close structural resemblance to typical localities near the Pennsylvania line. Such occurrences are of great interest from the theoretical standpoint.

In some portions of the field the Pittsburg coal bed shows a tendency to wide separation of parts, somewhat like that observed in the anthracite beds and in the Pottsville beds of the Kanawha region. In the Potomac basins of Maryland and West Virginia the several portions of the bed are separated by shales and clays, so as to occupy a vertical space of 40 to 63 feet; in the Salisbury basin of Pennsylvania the bed and its partings are in a vertical space of 46 feet at the southern end, but this increases to about 160 feet at the northern end, with shales, sandstones, and limestones in the intervals; in the Connellsville basin one finds at a few miles south from Uniontown, in Fayette county, the Pittsburg in all about 14 feet thick and 30 feet below the Redstone coal bed; but northward the Pittsburg interval quickly increases to 58, 66,

and 68 feet, the interval to the Redstone coal bed decreasing to 25 feet. The upper coal layers of the Pittsburg disappear northward, but the interval from the "Main" coal to the Redstone decreases very slowly and becomes normal only as one approaches the north end of the basin. A similar condition exists in southern Fayette within the Lisbon basin, but the divergence as well as the area in which it occurs is not so great; farther west in Pennsylvania and Ohio the tendency to local irregularity of deposit is shown by the presence of "rider" coal beds at many localities.

The Pittsburg sandstone (H. D. Rogers, 1858) is a variable rock overlying the Pittsburg coal on the borders of the basin, but it is far from being persistent, the interval being filled with shale very frequently. A thin deposit of shale usually intervenes between the coal and the sandstone. This coarse deposit is present commonly along the northern outcrop in Pennsylvania as well as in the Connellsville basin and southward in the exposed area of West Virginia; it is important along the southern edge of the field in that state into Ohio, where it is almost constant in Gallia, Meigs, and Morgan counties on the south and west border; but northward from Morgan, on the western border, it is wanting until one comes to western Belmont, Guernsey, and Harrison. Its distribution in Ohio lends probability to the suggestion already offered respecting the western extent to the Pittsburg coal bed. This sandstone is confined practically to the borders of the field, and within the interior portions one finds shale with only occasional sandstone in the interval.

The Redstone limestone (J. J. Stevenson, 1877) is confined to the north central part of the field, being absent along the northern outcrop in Pennsylvania as well as in nearly the whole of West Virginia and Ohio. Like the other limestones of this formation, it is non-fossiliferous or at the most contains minute forms which may be of fresh-water types. It persists in Pennsylvania between Chestnut ridge and the Ohio river and is present in eastern Belmont of Ohio; it disappears quickly south from the Pennsylvania line in West Virginia. Perhaps it may be the "limestone group" of Andrews in southeastern Ohio, but that can be no more than a mere suggestion; for, as indicated by Professor Andrews more than 30 years ago, these limestones appear to be irregular deposits of calcareous mud and are given to sudden variations. Within Pennsylvania and the immediately adjacent part of West Virginia the correlation is exact.

The Redstone coal bed (H. D. Rogers, 1858) is very persistent in the northern part of the basin, though rarely attaining sufficient thickness

to be of local importance. It is from 30 to 80 feet above the "Main" coal of the Pittsburg and its place is almost invariably marked by coal or by richly carbonaceous shale. In many localities where it is wanting its absence is due to erosion during deposition of an overlying sandstone, continuous downward with the Pittsburg. Sometimes it is of workable thickness in southern Pennsylvania and adjacent part of West Virginia near the Monongahela river. The identification of the bed is very clear in Pennsylvania, West Virginia, and Belmont county of Ohio, but the reference of isolated bits of coal in southern Ohio is tentative to the last degree. They may be only "rider" coals to the Pittsburg. A feature of the Redstone in much of Pennsylvania is the occurrence of broad clay veins in localities where the underlying Pittsburg coal bed is undisturbed. The bed is roofed ordinarily by shale or sandstone and is often only an inch or two above its limestone. At one place in Washington county, Pennsylvania, it has a limestone roof.

The Fishpot limestone (J. J. Stevenson, 1876) has been regarded as equivalent to the Sewickley limestone (F. and W. G. Platt, 1877), but the relations of the latter limestone are very uncertain and in all probability it is not the same with the Fishpot. This limestone is separated at most by 5 or 6 feet from the Lower Sewickley coal bed, and occasionally the two deposits are apparently in contact. It seems to be wanting east from the Alleghenies as well as in the eastern basins and along the northern outcrop in Pennsylvania; but it seems to be persistent, though extremely variable, in most of the area west from Chestnut ridge across Pennsylvania into northern Ohio as well as southward for 30 miles in West Virginia. It is thick in some of the Pennsylvania basins and thin or uncertain in others. It becomes very thick in the basins of Fayette and Westmoreland as well as in the adjacent portions of Washington and Greene, sometimes 30 feet, and it is equally important on the Ohio river. This deposit is confined to the northern part of the basin and, like most of the other limestones in the formation, seems to be wholly wanting in the interior part. Its interval rarely carries any limestone in Ohio south from northern Monroe county.

The Sewickley coal bed (H. D. Rogers, 1858) includes two coal beds; the lower bed rests on the Fishpot limestone or is separated from it by thin clay, while the upper bed overlies the Sewickley sandstone and is almost directly under the great Benwood limestone. One seldom sees both beds well defined in a single section. The type sections obtained by the geologists of the First survey as well as by those of the Second survey were obtained in southern Fayette and Greene counties near the West Virginia line, where the Sewickley sandstone is unusually

variable; there was supposed to be only one bed and the conditions there observed were applied throughout the Pennsylvania areas. Later studies, supplemented by records of shafts and borings, make it possible to correct the writer's error of 30 years ago.

The Lower Sewickley coal bed is the Sewickley of most of Greene, Washington, and Allegheny counties, Pennsylvania, as described in volume K of the Pennsylvania reports. It is the persistent bed of Fayette and Westmoreland counties within the Connellsville basin, but it is very indefinite in the Lisbon. The horizon is well marked by the Fishpot limestone below and the Sewickley sandstone above, between which one usually finds either coal or black shale. The bed is of workable thickness at some localities in Fayette and Greene counties of Pennsylvania and it is a well marked coal horizon in West Virginia, being noted in very many oil-well records at 25 miles south from the Pennsylvania line. In northern Ohio it is present in Belmont and perhaps Monroe county as coal, but very thin. Its extent is much less than that of the Pittsburg, the interior area in which it is wanting being much greater.

The Sewickley sandstone (I. C. White, 1891) is a remarkably persistent deposit, 5 to 40 feet thick, recognized throughout Pennsylvania and northern Ohio and very distinct in West Virginia to at least 40 miles south from the Pennsylvania line. It is present in many oil-well records, even into the central area of West Virginia. Near Uniontown, in Fayette county of Pennsylvania, it is wanting in a shaft where the Sewickley coals have united, the resulting bed separating the Fishpot and Benwood limestones. In the southwest part of that county the sandstone gradually decreases and the Upper Sewickley coal bed is let down almost to the Fishpot limestone.

The Upper Sewickley coal bed. Maryland: Gas, Tyson. Pennsylvania: Sewickley. West Virginia: Sewickley. Ohio: VIIIc, X, Cumberland, Meigs creek, Macksburg, Upper Barnesville.

This is an important coal bed near Frostburg, in Maryland; it is unimportant in the Connellsville basin, where one finds at its horizon only black shale, but in western Fayette and Westmoreland it is persistent as coal, almost directly underlying the Benwood limestone; and there, as in the adjacent portions of Washington county, it is occasionally thick enough to be mined. In much of Washington and Allegheny counties it is little more than black shale, but when it comes up again on the westerly side, in the West Virginia panhandle, it is coal in two or three

divisions with varying intervals. There, as in Jefferson and eastern Belmont of Ohio, it is unimportant; but in western Belmont and Harrison it becomes more important than the Pittsburg. In much of Ohio it is the chief source of supply, although its coal usually contains more ash than that of the Pittsburg. Where best developed it is a triple bed, the middle bench being thick, the other, separated from it by thick clay partings, being too thin to be worked. It extends much farther eastward into the barren area than the Pittsburg does; it is the important Macksburg coal of southern Noble and northern Washington at 25 miles southeast from the disappearance of the Pittsburg; but it becomes irregular and of little value further toward the middle of the trough. It is insignificant in West Virginia, but a trace of it was seen on the Baltimore and Ohio railroad west from Clarksburg, in Harrison county, and it may be the coal reported in some records termed the Sewickley in the following pages. While the horizon is well marked in much of Pennsylvania and occasionally carries workable coal in small areas there, as in Maryland, it is most thoroughly characteristic of the westerly side of the trough, where within its present area it has more coal than the Pittsburg. Judging from conditions shown by the latter bed, which reaches 9 feet on the western outcrop in Morgan county, one should expect the Upper Sewickley to increase greatly toward its western outcrop; but the contrary is true, as, accordingly to Professor Brown, the Upper Sewickley "is thin and unsteady and of little economic value" in western Morgan, whereas it is important in eastern Morgan as in Noble, southeast Muskingum and southern Guernsey. But is a coal bed to the western outcrop.

The Sewickley horizon was characterized by local irregularity of deposit. Reference has been made to the disappearance of the Sewickley sandstone and its rapid reappearance in southern Fayette of Pennsylvania. In southern Greene county, Doctor White found the Lower Sewickley, 4 feet 10 inches thick and in several benches; but at half a mile away these benches are distributed in a vertical space of 33 feet 6 inches. On Wheeling creek, 3 miles east from Wheeling, West Virginia, the section is:

	Feet	Inches	Feet	Inches
Upper Sewickley coal bed:				
Coal	1	2		
Fireclay, sandstone	6	4	8	6
Coal and shale	1	0		
Clay and Sewickley sandstone			14	0
Lower Sewickley coal bed			1	8

in all 24 feet 2 inches. A section in Wheeling shows the Upper Sewickley 3 feet thick and 17 feet above the Lower Sewickley, also 3 feet, a vertical space of 23 feet; but at another place in Wheeling, Doctor White found the three beds once more and in a vertical space of 43 feet. At 12 or 14 miles below Wheeling, on the Ohio, Doctor White's section shows the Upper Sewickley 2 feet thick and separated by 12 feet of Sewickley sandstone from 10 feet of coal and shale apparently representing the Lower Sewickley. The varying interval between Upper Sewickley and Pittsburg along the western outcrop suggests similar irregularities in that region.

The Great limestone (H. D. Rogers, 1858) included all of the limestone bed in the Monongahela formation. In 1876 J. J. Stevenson restricted this term to the deposits between the Upper Sewickley and the Uniontown coal beds, and divided it into Lower and Upper; in 1877 he applied the term Uniontown to the upper division, and in 1903 Doctor White designated the lower division as the Benwood.

The Benwood limestone (I. C. White, 1903) is almost directly above the Upper Sewickley coal bed. It seems to be wanting east from the Alleghenies and is very thin along the northern outcrop in Pennsylvania, though some trace remains in the Ligonier, Connellsville, and Lisbon basins almost to the last exposure. Farther west in Allegheny and northwest Washington it is either wanting or very thin. Southward it comes into the section rather abruptly, attaining great thickness almost at once. It is not always continuous limestone, but sometimes is very largely calcareous shale, and at others is broken by shale or sandstone beds. It reaches its maximum thickness in Fayette and Westmoreland within the Lisbon basin, and retains it along the Monongahela river in much of Greene and southern Washington. It is from 60 to 90 feet thick in that area and in some places is continuous with the Uniontown limestone above. This great thickness continues for a little way into West Virginia, but it quickly becomes insignificant, and in less than 40 miles there is barely as much as 7 feet in this interval. It seems probable that the mass persists under Greene county of Pennsylvania, for where the rocks come up again near the Ohio river it is very thick and so prominent that the name is given from Benwood 4 miles below Wheeling.

In Ohio this limestone is wanting within northern Jefferson, Harrison, and northern Guernsey counties; it is thick in eastern Belmont and southern Jefferson, but in the western part of the former county it is broken into many layers, varying in thickness and separated by shales or sandstones. The Benwood interval contains limestone beds along

much of the western outcrop, and, as in Pennsylvania, some of the more persistent beds are magnesian, being referred to by Andrews as "cement beds." Southwardly it is replaced by sandstone, sometimes 60 feet thick and often very coarse, so that the Upper Sewickley is known as the "Sandstone coal" to distinguish it from the Pittsburg or "Limestone coal."

The interval of 20 to 40 feet between the Benwood and Uniontown limestones is occupied usually by sandstone or sandy shale.

The Uniontown limestone (J. J. Stevenson, 1877) is one of the more persistent members of the section. It is wanting east from the Alleghenies, but is present throughout the Connellsville basin, is apparently one of the upper limestones near Greensburg, is everywhere in the Lisbon basin south from the Pennsylvania railroad, extends to the most northerly outcrop of its place in Allegheny county, and seems to be present everywhere in Washington and Greene where its place is exposed. It is present in northern West Virginia toward the eastern outcrop, but diamond-drill cores do not show it toward the west. It evidently disappears southwardly at no considerable distance from the state line. It is present in the northern panhandle of the state, and in Ohio one finds limestone at this horizon in by far the greater part of the area when the place is exposed. In much of Pennsylvania it has a characteristic yellow color on the weathered surface, wholly unlike that of any other limestone in the formation. The thickness varies from 2 to 12 feet.

The Uniontown coal bed......Maryland and Pennsylvania: Uniontown.
H. D. Rogers, 1858. West Virginia: Waynesburg, Macksburg, Uniontown. Ohio: Hobson, Cumberland, Waynesburg, Clarington.

This bed is rarely of interest or importance on the northeasterly side of the great basin, where it was first studied and named. Its insignificance in that region caused failure to recognize it in other regions. Doctor White's suggestion, that the West Virginia bed, usually referred to the Waynesburg, might prove to be the Uniontown, proves to be correct. The bed is present as coal, but very thin, in Maryland; its place is marked by shale or coal almost everywhere in the Connellsville basin, but it is not a workable bed anywhere, for, though thick enough near Uniontown, its coal is very bad. In the Lisbon basin it is present to the most northerly exposure, but for the most part is very thin, except in some places within Fayette and Greene counties, where it is opened occasionally by farmers, but yields miserable coals. Farther west the coal does not extend northward into Allegheny or northwestern

Washington, but it is shown frequently south from the line of the Pennsylvania railroad in the latter county, though never more than about 2 feet thick and always apparently very inferior. It is seldom more than 2 or 3 feet above its bright yellow limestone and at times the coal and limestone are separated by a mere parting shale. The bed is present in the northern panhandle of West Virginia and is distinct in western Belmont of Ohio, though wanting in Jefferson, Harrison, and apparently in northern Guernsey. It does not seem to reach the northern outcrop in Ohio, reaching northward there hardly any farther than in Washington county of Pennsylvania; but southward it is persistent as shale or coal along the western outcrop, where it is known as the Hobson coal bed and is occasionally workable. It is of considerable local importance in northern Monroe, where it has a somewhat complex structure. It is certainly present under the Cowrun anticline in Washington county and northward along the Ohio river, but southward it evidently disappears. It is insignificant in the exposed area within the eastern part of the West Virginia field, but it is distinctly a coal bed in Harrison, Doddridge, Gilmer, Lewis, and Wirt, in all of which it is exposed and at times shows a structure recalling that seen in Monroe of Ohio. The records of oil borings show that it is present in all counties north from the Little Kanawha river except possibly Wood, where every trace of coal seems to have disappeared in this formation. Its occurrence farther south is very doubtful and it is not reported in any record.

The distribution of the Uniontown contrasts notably with that of the lower beds. The Pittsburg is practically absent from the great interior area, though its horizon is marked often by thin coal or by carbonaceous shale; it is a thick bed on the borders of the field, thinning from all sides toward the middle. The Upper Sewickley is insignificant for the most part on the east side, though its place is rarely without shale or some coal, but on the west side it is important, extending southward to many miles beyond the Pittsburg's disappearance, though, like that bed, marked only by black shale or wholly wanting in the central buried area. The Uniontown, however, always thin and never attaining more than purely local importance, is a well marked coal horizon west from Chestnut ridge, and even from farther east in West Virginia, across the whole basin. It is a distinct coal horizon in the central part of the field, where the lower beds have become indefinite, and does not disappear southwardly until one approaches the region where the Pittsburg reappears. Though a coal bed in a so great area, it shows no regular variations in thickness such as those of the Pittsburg, but is a thin sheet, usually

double, sometimes still further divided. Its peculiarities possess much interest, considered in reference to the origin and accumulation of coal beds. The carbonaceous shale at this horizon usually contains fragmentary remains of fish, with small lamellibranchs and other forms of undetermined relations. In Monroe of Ohio and Doddridge of West Virginia it is associated with plant-bearing shales. Near Uniontown, Pennsylvania, it underlies an impure limestone containing lamellibranch shells.

The interval between the Uniontown and Waynesburg coal beds is the most variable in the formation. In Marion county of West Virginia the Waynesburg coal bed is somewhat more than 100 feet above the Uniontown limestone, but this interval decreases northward until, in Allegheny and northern Washington of Pennsylvania, the coal and limestone are practically in contact.

The Uniontown sandstone (I. C. White, 1891) is a rather persistent deposit occupying much of the interval, though, like other sandstones, it is apt to be replaced rather abruptly by shales. One finds it very frequently in southern Pennsylvania, at times tenacious enough to form cliffs, but only moderately coarse in grain and very seldom containing pebbles. It shows the same features in much of the exposed area in West Virginia as well as across the northern portion of the state, as appears from oil-well records; but farther south, in Lewis, Gilmer, Doddridge, Tyler, and Pleasants counties, a broad band crossing the state from east to west, the sandstone is massive, coarse, and even conglomerate, exposed in many places and recorded elsewhere in oil wells. It is one of the "Carroll" sands in Ritchie county. In Washington, Morgan, and Athens of Ohio the band continues and the rock is the 200-foot conglomerate of Professor Andrews. Northward and apparently southward from this strip the conglomerate is wanting, the sandstone, where present, is fine grained, and in broad areas the interval is filled by shales. This conglomerate, much resembling that above the Waynesburg coal bed, proved a stumbling block in correlation. It geographical distribution is puzzling.

The Waynesburg limestone (J. J. Stevenson, 1877) is in the upper part of the interval between the coal beds and is of wide extent. It is from 10 to 40 feet below the Waynesburg coal bed. It is present in Maryland and it may be part of the thick limestone in Broad Top; it seems to be present throughout Fayette and Westmoreland counties wherever its horizon is reached, but is wanting in Allegheny and northern Washington, where the Waynesburg coal bed approaches closely to the Uniontown limestone; yet it was seen farther south in Washington,

and in that county as well as Greene it is absent from few sections in which its place is exposed. It disappears quickly southward in West Virginia, where it is without representative almost everywhere in the exposed area. It persists across the northern panhandle into Belmont county of Ohio, but thence there is little information respecting it, as few detailed sections extend above the Uniontown (Hobson) horizon. An impure limestone is reported occasionally at 30 to 40 feet above the Uniontown coal bed.

A sandstone sometimes appears between this limestone and the Waynesburg coal bed, but it is unimportant except in western Marion and northern Harrison of West Virginia, where it is massive and extends downward below the place of the limestone. This was termed the Gilboy sandstone by Doctor White.

The Little Waynesburg coal bed (J. J. Stevenson, 1876) is an unimportant horizon, economically, as the coal rarely attains workable thickness. Like the Uniontown, its areas of moderately thick coal are far away from the borders of the field, as marked by the Pittsburg and Waynesburg coal beds. It is found commonly as a thin coal, one foot or less, at very many places in southwest Pennsylvania and immediately adjacent parts of West Virginia, but it seems to be wanting in Maryland, Ohio, and practically all of West Virginia. It is separated by a variable interval from the limestone below.

The Waynesburg coai bed......Maryland: Koontz, Waynesburg. Pennsylvania and West Virginia: Waynesburg. Ohio: Tunnel, XI.
H. D. Rogers, 1858.

This bed, at the top of the formation, is a notable deposit in the northern part of the field and is apparently present wherever its horizon is reached in Maryland, Pennsylvania, northern Ohio, and northern West Virginia. Measurements in Pennsylvania are almost as numerous as are those of the Pittsburg, and it is the principal source of domestic supply in considerable areas, though its coal is so inferior that the bed rarely attains commercial importance. It is thin, 2 to 4 feet, including partings, along the northern border in Pennsylvania and in Ohio. In the latter state it is usually very thin and it seldom appears in sections south from Belmont county. Traces of it are reported occasionally in Morgan, Monroe, and Noble counties, while in Meigs and western Washington a thin coal bed sometimes appears under the upper conglomerate of Andrews. The bed is present at Wheeling on the Ohio, but farther south becomes thin and apparently disappears within 30 miles.

In its full development the bed is double, triple, quadruple, or even

more divided and the parting clays show abrupt variations in thickness. This subdivision is characteristic not only in southwest Pennsylvania, but also in Maryland, where the coal is mined on commercial scale. The extreme subdivision was seen in northern Greene county of Pennsylvania, where the measurement is:

	Feet	Inches
Coal	1	0
Clay	1	0
Bone	0	6
Coal	1	3
Clay	0	6
Coal	2	2
Clay	3	0
Coal	0	3
Clay	0	4
Coal	0	5
Shale	10	0
Coal	0	8

in all, 21 feet; but the lowest parting quickly decreases to 2 feet and soon disappears, as do most of the others; so that within 3 miles the bed is double, averages 6 feet in thickness, and shows these variations:

	Inches
Coal	12 to 18
Clay	12 to 48
Coal	12 to 42

The Waynesburg coal bed is persistent in Monongalia, Marion, eastern Wetzel, northern Doddrige, and northern Harrison of West Virginia, with its chief thickness at the east in the first two counties, where it at times reaches to almost 12 feet, inclusive of the moderately thick partings. Southwardly it disapepars or is so thin that drillers of oil wells thought it not worth recording. It is wanting along the southeastern and southern outcrop, except perhaps at Arbuckle, in Mason county, where Doctor White found a multiple coal bed 268 feet above the Pittsburg and underlying a pebbly sandstone. This overlying rock resembles very closely that seen 240 to 250 feet above the Pittsburg at Antiquity, on the Ohio river, 20 miles north from Arbuckle. That is the Waynesburg sandstone of the Dunkard. The sandstone observed at Arbuckle seems to be persistent on the southern outcrop, but the underlying coal bed is not.

Red beds are unimportant in by far the greater part of the Monongahela area; they appear to be wholly absent from Maryland, Pennsylvania, northern Ohio, and insignificant along the northern border of

West Virginia. The important locality is in the central region, within West Virginia and Ohio, where are the great reds of the Conemaugh, some of them extending downward into the Allegheny.

Red beds appear in the Pittsburg-Upper Sewickley interval within the south central counties of Ohio, Monroe, Washington, Morgan, Athens, and Gallia, as well as in Wood, Ritchie, Gilmer, Calhoun, and more southern counties of West Virginia. Farther north the only occurrence of red is in Wetzel, where 5 feet are on the Pittsburg coal bed. The greatest thickness is in Calhoun, Mason, Wood, and Ritchie of West Virginia, where the mass beginning at or below the place of the Pittsburg is at times more than 100 feet thick.

A widespread deposit is in Ohio at 18 to 46 feet above the Upper Sewickley and varies from 52 to 14 feet in thickness. It appears in many sections from southern Guernsey through Monroe, Morgan, Washington, and Meigs, and it is thicker in Tyler, Ritchie, and Wood counties of West Virginia. For convenience of reference, this may be designated as the Tyler reds. Another deposit, equally well marked, underlies the Uniontown coal bed or its place and is reported from southern Marshall, Marion, Wetzel, Doddridge, Tyler, Ritchie, Jackson, southwest Harrison, and northeast Gilmer of West Virginia, as well as in Washington, Monroe, Meigs, and Guernsey of Ohio. Its place is concealed in most of the published sections from Ohio. It is rather thin in that state, seldom more than 20 feet, but in Ritchie, Gilmer, and elsewhere in West Virginia it is very thick and at times continuous with the Tyler reds below. Reds occur at this horizon in counties south from those mentioned, but they are not differentiated in the records. This mass, which may be termed the Ritchie reds, has much greater extent than the Washington reds of the Conemaugh, but much less than the Pittsburg reds. The chief area of reds is in Wood and Ritchie of West Virginia, where there is hardly a foot of the Monongahela section which is not occupied in some well or other by red shale.

The variation in thickness of the Monongahela—that is, of the interval between the Pittsburg and Waynesburg coal beds—is greater than that of the Conemaugh, the interval between the Upper Freeport and Pittsburg beds. The variations in these two formations do not coincide geographically. The greatest thickness of the Conemaugh is in Allegheny county of Pennsylvania, at the most northerly exposures of the Pittsburg, and that thickness decreases very slowly southward, losing barely 50 feet by the time the southern line of the state has been reached. Eastwardly the decrease is small, the interval being practically as large in Maryland as in southern Pennsylvania. Along the eastern border

in West Virginia the change is slight, but the decrease is notable toward the west, for in Ohio the interval becomes little more than half that north from Pittsburg.

In the Monongahela the greatest thickness, somewhat more than 400 feet, is in Marion and northern Harrison of West Virginia. Northwardly this decreases gradually, until in northern Washington of Pennsylvania it is but 166 feet at least 20 miles south from the line of the last exposure in Allegheny county. There is a similar decrease eastwardly, for it quickly becomes 350 feet, while in Maryland it is barely 250 feet. Westwardly the decrease is slow for 25 or 30 miles, but thence more rapid, so that in Ohio the interval is barely 240 feet. In that state there is a decrease northwardly, and at the last exposure in Jefferson county it is but 140 feet, this locality being northwest from the last measurement in Pennsylvania. Toward the south, southeast, and southwest the story is the same. The area of deepest deposit is in southern Greene and Fayette of Pennsylvania, Monongalia, Marion, eastern Wetzel, northern Harrison, Doddridge, and eastern Tyler of West Virginia.

EAST FROM THE ALLEGHENIES

Broad Top.—Fifty years ago Professor J. P. Lesley recognized the Pittsburg coal bed in the Broad Top area of Bedford county, where it remains in a tract of somewhat more than a square mile. Stevenson says that it is reported 5 feet thick, but the coal has never been utilized and the thickness as given is probably excessive. A limestone 12 feet thick is at 200 feet above the coal, and at somewhat less than 275 feet is another coal bed, belonging probably in the Dunkard formation.*

Maryland.—Some small areas of great commercial importance remain in Allegany and Garrett counties of Maryland, showing the full section; others in Mineral county of West Virginia are very small and retain only the lower part of the formation. The rocks throughout are tender and disintegrate readily, while the sandstones are rarely thick enough to affect the topography, so that sections in detail are obtained only in shafts or borings. Messrs O'Harra and Martin give this succession from a shaft near Frostburg, in Allegany county:

	Feet	Inches
1. Koontz [Waynesburg] coal bed	1	10
2. Concealed	20	0
3. Waynesburg limestone	5	7
4. Sandstone and shale	31	3
5. Uniontown coal bed	0	5
6. Sandstone and shale	57	10

* J. J. Stevenson: Bedford and Fulton counties (T 2), pp. 59, 60, 249.

	Feet	Inches
7. Sewickley [Tyson] coal bed................	5	6
8. Shale and some sandstone..................	46	0
9. Coal bed [Redstone]........................	2	6
10. Shale, sandstone, and shale................	28	4
11. Limestone	5	6
12. Shale	7	8
13. [Pittsburg] coal bed........................	40	4

	Feet	Inches
Coal and shale............	7	4
Shale	19	11
Coal and shale.............	3	7
Main coal	9	6

The Waynesburg or Koontz bed is 8 feet 5 inches at Koontz, in Garrett, and 6 feet at Lonaconing, in Allegany. As at the west, it is triple to quadruple, with, at one locality, broad clay veins. It is from 90 to 115 feet above the Sewickley or Tyson coal bed. The thin streak referred to the Uniontown coal bed was observed only in this shaft, its place being concealed elsewhere. The Sewickley is an important coal bed, single, double, or even more divided, with at times nearly 5 feet of coal and thicker toward the southern end of the area. The coal bed, Number 9, thought by the Maryland geologists to be possibly the Lower Sewickley seems rather to be the Redstone. The assignment of the lower part of the section to the Pittsburg horizon is in accord with Doctor White's original suggestion respecting the section in Mineral county of West Virginia and it is rendered the more probable by conditions farther west. The following measurements show the variations in the bed:

	Feet	Inches	Feet	Inches
Coal and shale....................	7	4	8	3
Shale	19	11	22	6
Coal and shale....................	3	7	12	6
Coal	9	6		
Total.........................	40	4	43	3
Coal	4	6	2	0
Shale	2	0	6	0
Coal	1	0	9	6
Shale	4	9	16	0
Coal	0	10	4	6
Shale and S. S....................	6	11	18	0
Coal	14	0	7	0
Total.........................	34	0	63	0

The measurements are from the Consolidated shaft, the Borden shaft, Lonaconing and Mineral county of West Virginia, arranged in the order from north to south. At Lonaconing one finds about 20 feet of coal in a total of 34 feet; at the Borden shaft the carbonaceous matter is distributed throughout 22 feet of black shale between the highest portion and the Main coal. The lowest division is known throughout as the "Big vein." The interval from the Waynesburg to the Pittsburg as here described is 205 to 211 feet.*

WEST FROM THE ALLEGHENY MOUNTAINS, IN PENNSYLVANIA

The First and Second bituminous basins.—A small area of Monongahela, known as the Salisbury basin, remains within the First basin in Somerset county at about 50 miles southwest from Broad top and 20 miles northwest from Cumberland, in Maryland. It embraces about 20 square miles and extends from near Meyersdale southward almost to the Maryland line. Its great coal bed was identified with the Pittsburg by Professor J. P. Lesley in 1839. The area was examined in 1876 by F. and W. G. Platt and J. J. Stevenson, who, while agreeing as to the measurements, by no means agreed respecting the relations of the beds. † The section at the north end of the area, as given by the Messrs Platt, is:

	Feet
1. Coal bed, Uniontown	2
2. Clay	1 to 6
3. Limestone	10
4. Slates	42
5. Black slate	3
6. Coal bed	1
7. Clay	1
8. Black slate	15
9. Coal bed	Blossom
10. Limestone	5
11. Concealed	52
12. Coal bed, Redstone	Blossom
13. Concealed	15
14. Black shale	10
15. Pittsburg coal bed	10

This section is distinct for three miles southwardly to near Salisbury,

* P. T. Tyson: Second rept. Agric. Chemist, 1862, pp. 46, 47.
C. C. O'Harra: Allegany county, pp. 125, 126, 127, 177, 180.
G. C. Martin: Garrett county, pp. 141, 142.
I. C. White: U. S. Geol. Survey Bulletin, no. 65, pp. 56, 63.

† But Stevenson in his report on the Fayette and Westmoreland district accepted the conclusions of his colleagues, as they had been adopted by the Director of the Survey.

beyond which the sudden southward rise of the measures and decrease in height of the hills prevent direct tracing of the higher beds. To increase the difficulty, the continuity is broken by a broad valley, cut down to the Pittsburg coal bed, whose decayed outcrop is on the surface.

The highest coal bed is double, 2 feet 2 inches at the most northerly exposure and 2 feet 9 inches at 2½ miles from Meyersdale. The underlying limestone, 152 to 160 feet above the Pittsburg coal bed, the 160-foot limestone of the Platts, is 10 to 12 feet thick and continuous at the northern exposure, but at the most southerly exposure of the full section it is divided, with 2 feet of coal above the middle. It is quarried at several places and always yields lime of great purity. The limestone, No. 10, from 72 to 87 feet above the Pittsburg, the 90-foot limestone of the Platts, is 5 feet thick at the northern exposure, but increases to 10 feet at 2 miles northwest from Salisbury. It has been opened at a few places, but it is very impure everywhere, contrasting in this respect with the upper limestone.

The "Redstone," or 44-foot coal of the Platts, is 25 feet above the Pittsburg in one section and 35 feet above that bed in three other sections, of which the most southerly is about 3 miles southwest from Meyersdale. The material filling the interval in these sections is the same throughout—sandstone, 15 feet; black shale, 20 feet. The compiled section for Salisbury given in the Somerset County report is erroneous, as it shows a limestone below the "Redstone," which, as may be seen by reference to the text, does not exist there—or, as for that matter anywhere else. There is no coal between the Pittsburg and the "Redstone," and the latter coal at the last exposure of the typical section shows:

	Feet	Inches
Coal	2	0
Parting	—	—
Coal	1	3
Clay	0	1
Coal	1	3

but at half a mile away it is 5 feet 6 inches thick, with the bottom bench 4 feet. Here one reaches the broad deep valley, beyond which the section is:

	Feet	Inches
Limestone	Not measured	
Interval	65	0
Coal bed	4	6
Black shale	11	0
Pittsburg coal bed	Not measured	

but at a mile west from Salisbury this limestone is only 55 feet above the coal bed, which is 13 and at another exposure 18 feet above the Pittsburg. The coal bed is triple, 6 feet 1 inch thick and with the thick bottom bench seen at the last exposure of the "Redstone." Black shale seems to fill the interval to the Pittsburg. No trace of coal appears at 35 to 40 feet above the Pittsburg, nor is any coal found at that horizon anywhere south from a line passing east and west at 3½ miles southwest from Meyersdale. The coal bed, 11 to 18 feet above the Pittsburg, is evidently the "Redstone" and the decreased interval is due to disappearance of the sandstone. Followed southward, this bed, termed the "rider" in the Somerset county report, constantly approaches the Pittsburg, the interval becoming 6, 4, and 1 foot. Very near the southern end of the area, Mr W. G. Platt measured:

	Feet
1. Concealed	15
2. Ferruginous sandstone	9
3. Concealed	11
4. Coal bed	Blossom
5. Clay	6
6. Limestone	10
7. Concealed	12
8. Coal bed	4
9. Slate	4
10. Pittsburg coal bed	10

and the coal bed, Number 4, exposed near by, is very like the "Uniontown" of the northern section. It is taken to be the "Redstone" in the Somerset County report. The underlying limestone is almost exactly the same in composition with the 160-foot limestone at the north, the variation being barely one per cent in any constituent. It disappears quickly southward and the Ferruginous sandstone is very near the Pittsburg at the most southern exposure.

Stevenson's conclusion was that this limestone at the southern end is the 160-foot limestone of the northern end; that the coal overlying it is the "Uniontown," and that the "rider" of the southern is the "Redstone" of the northern portion. He regarded all the higher beds as splits from the Pittsburg, but he was unable to correlate them with beds farther west.

The Pittsburg coal bed shows unusually abrupt variations in structure and quality. At the north it is divided into many benches and the section at one pit cannot be duplicated at another. Southward from Salisbury it is apparently solid coal in the 8 feet above, but the foreign mat-

ter seems to be distributed throughout so as to increase the ash. The thickness varies from 8 feet 6 inches to 9 feet.*

Some small patches remain within the Second basin north from Ligonier, in Westmoreland county, at about 40 miles northwest from the Salisbury basin. The measurements are:

	Feet	Inches
1. Limestone	6	0
2. Concealed and thin limestones	111	0
3. Coal or coaly shale	0	6
4. Clay	3	0
5. Limestone	8	0
6. Shale and sandstone	28	0
7. Clay	2	0
8. Limestone	4 to 10	0
9. Coal bed	2	9
10. Shale	17 to 37	0
11. Pittsburg coal bed	8	0

It is difficult—indeed, impossible—to make positive correlation of the beds above the Pittsburg. The interval, Number 10, decreases northward, the measurements being 3 miles apart. This locality is far north for Monongahela and, compared with the Blairsville-Connellsville basin a few miles west, the limestone is in great excess. It is quite possible that the highest limestone belongs within the Dunkard. The Pittsburg shows traces of a roof division, apparently wanting in the Salisbury basin, there being on top at most of the pits from 8 to 12 inches of coal and slate interleaved. The main coal is usually 8 feet thick and is in five benches, in which the character of the coal differs. The "bottom," about 8 inches, is very poor, but the second, 2 feet thick, is very good; the third, ordinarily less than 1 foot, is broken by many binders of clay and mineral charcoal; the fourth, about 2 feet, is prismatic, tender, and very pure, while the top bench is hard coal, often containing some cannel.†

The Blairsville-Connellsville basin.—This following the westerly foot of Chestnut ridge, the last great fold of the Appalachian in Pennsylvania, may be regarded as practically continuous from the Kiskiminetis river at the north across Fayette and Westmoreland counties to within a few miles of the West Virginia line at the south. The section rarely extends much above the Waynesburg coal bed, the rocks yield readily to

* F. & W. G. Platt: Somerset county (H 3), pp. 78, 83, 85, 86, 89, 93, 94, pl. vi, figs. 29, 30, 31, 32, 33, 39.

J. J. Stevenson: Fayette and Westmoreland (K 2), pp. 40, 41, 53, 54.

† J. J. Stevenson: Fayette and Westmoreland, pt. ii (K 3), pp. 14, 152, 153, 167, 168, 169.

the weather, and the surface for the most part is gently rolling, so that natural exposures are comparatively rare.

On the Pennsylvania railroad, about 8 miles south from the Kiskiminetis river, some cuts give opportunity for approximate measurement; two imperfect sections were obtained, one at a mile and a half, the other at 5½ miles north from the railroad, and Mr Platt gives a measurement in Indiana county at a short distance north from the river. These may be compared.

	Feet	Inches	Feet	Feet	Inches	Feet
1. Sandstone				Not measured		Not measured
2. Coal bed...............				Blossom		Blossom
3. Sandy shale...........				15	0	15
4. Limestone				5	0	Fragments
5. Interval						
6. Coal bed...............			Blossom			
7. Shales	30	0	30	75	0	60
8. Limestone	1	6	Fragments			
9. Clay, concealed, and sandstone	40	0				
10. Coal	0	8		Blossom		Blossom
11. Shale	7	0	70	5	0	
12. Coal	0	10				
13. Limestone	1	6		1	6	
14. Shales	35	0				44
15. Coal bed	0	8	Blossom			
16. Clay, calcareous shale...	4	6	50	60	0	
17. Interval	80	0				
18. Pittsburg coal..........	9	0	Blossom	Blossom		7

There is an error in the first measurement, and the interval from Number 8 to the Pittsburg is 161 feet; in the second it is 120; in the third the Lower Sewickley coal bed is but 66, and in the fourth only 44 feet above the Pittsburg. The highest coal bed, shown nowhere in the vicinity of the first two measurements, underlies a massive sandstone and seems to be at the Waynesburg horizon; so that the Monongahela appears to lose about 100 feet of thickness in 10 miles. This is in accord with conditions farther west along the northern outcrop.

Six miles south from the Pennsylvania railroad the interval, Waynesburg to Pittsburg, by barometer without regard to the dip, is 280 feet. The higher coal bed is triple, 4 feet thick, with 3 feet of worthless coal, and is separated by 25 feet of sandy shale from the Waynesburg limestone below. The Benwood limestone, practically absent on the railroad, is thick at 8 miles south, where it is 25 feet above the Lower Sewickley, which is about 4 feet thick. The Redstone horizon shows only black

shale. The roof division of the Pittsburg, rarely thicker than 3 inches north from the railroad, increases southwardly to 6 inches and 1 foot, and at 4 miles the bed shows:

Roof, 3-4 feet 4 inches; clay 1 to 18 inches; Main coal, 7 feet 9 inches,

the roof consisting of coal and clay interleaved. Eight miles farther south, near Mount Pleasant, the Waynesburg, underlying its sandstone, is 5 feet thick and 66 feet above the Uniontown coal bed. Here one sees the Little Waynesburg coal bed; the Waynesburg, Uniontown, and Benwood limestones are present and thick, the last two being separated by 30 feet of sandstone. The Lower Sewickley coal bed, underlying the Sewickley sandstone, is only 18 inches thick and 40 feet above the Redstone, which shows 2 to 4 feet of coal and is somewhat more than 80 feet above the Pittsburg.*

There are few exposures above the Pittsburg in northern Fayette county and erosion by tributaries of Jacobs creek and Youghiogheny river has removed much of the Monongahela. The conditions south from the Youghiogheny are little better, but records of shafts and borings are numerous and show notable variation in the lower part of the section, quite like those of the Potomac areas and the Salisbury basin.

The Waynesburg coal bed is exposed near Mount Braddock, about 6 miles from the river, where it is 4 feet thick and 71 feet 6 inches above the Uniontown coal bed, as measured in a boring there. Four miles farther south the interval is 77 feet. The Little Waynesburg is present at both localities, 31 and 25 feet below the Waynesburg and resting on the Waynesburg limestone. The Waynesburg and Uniontown limestones are persistent, though thin, to the last exposure of their horizons, and in the southern part of the basin the Uniontown coal bed underlies an impure limestone containing many small lamellibranchiates of undetermined relations. The lower part of the column is shown in the Leisenring shaft, 3 or 4 miles south from Connellsville, an exposed section at 3 miles southeast from Connellsville, and at the Leith shaft, 12 miles south. The measurements are:

	Feet	Inches	Feet	Inches	Feet	Inches
1. Limestone	29	0			25	9
2. Shale	3	0	52	0	21	3
3. Limestone	26	0			22	6
4. Shale or clay	5	0	15	0	9	6
5. Upper Sewickley coal bed	2	3	3	0	5	3
6. Sewickley sandstone or shale	30	0	25	0	0	0

* J. J. Stevenson: (K 2), pp. 266, 267, 271, 272, 273, 274, 279, 281, 283, 284. W. G. Platt: Indiana county (H 4), p. 157.

	Feet	Inches	Feet	Inches	Feet	Inches
7. Lower Sewickley coal bed	0	6	0	10	0	0
8. Fishpot limestone and clay	7	6	11	0	28	6
9. Shale and black shale	8	0	20	0	39	0
10. Redstone coal bed	2	0	4	0	5	11
11. Redstone limestone	14	0	5	0	13	9
12. Slates	24	0	25	0	24	0
13. Pittsburg coal bed						
Coal	0	2	1	0	1	0
Slate	31	0				
Coal	1	0	50	0	27	6
Slate	21	0				
Coal and slate	5	0	5	0	12	6
Main coal	10	0	10	0	10	0

Thus giving for the Pittsburg horizon the thickness of 68, 66, and 51 feet, decreasing southwardly.

Both of the Sewickley beds are present near the Youghiogheny and are separated by the Sewickley sandstone; but the sandstone disappears southwardly, and at Uniontown as well as at Leith there is only one bed, and that at the place of the Upper, while the Fishpot limestone has made a notable increase. The interval from the Benwood limestone to the Redstone coal bed shows a great increase southwardly, but that from the Redstone to the Pittsburg, as here defined, shows little change, only 3 inches. The interval from the Redstone coal bed to the main division of the Pittsburg decreases from 96 feet at Leisenring to 78 at Leith. The condition shown in the lower part of the section prevails certainly to some distance north from the Youghiogheny river, for at Connellsville a "rider" coal, one foot thick, is at 14 feet above the roof division. The decrease is slow in the northerly direction, for at Mount Pleasant, in southern Westmoreland, the Redstone is still a little more than 80 feet above the main division of the Pittsburg; but the decrease southwardly is rapid, for on the National road, at two miles southeast from Leith, the Redstone and Sewickley are 50 and 90 feet above the Pittsburg, both Redstone and Fishpot limestones being present. Six or 8 miles south from Leith the normal condition of the Pittsburg is found and a complete measurement along the road shows:

	Feet
Waynesburg coal bed	316
Uniontown coal bed	241
Lower Sewickley coal bed	80
Redstone coal bed	30

feet above the Pittsburg, with the Waynesburg, Uniontown, Fishpot, and Redstone limestones all present and the Sewickley sandstone over-

lies its coal bed. The Benwood is represented by several thin beds. Farther south the Lower Sewickley becomes variable, 1 to 5 feet, the Redstone coal is but one foot 6 inches and its limestone disappears.*

The Greensburg basin.—This is a canoe within central Westmoreland in which the Monongahela passes out southwardly at a few miles south from the Pennsylvania railroad. The strong Blairsville and Saltsburg anticlines separate it from basins at the east and west. It retains two small but important areas of Monongahela. The section reaches to fully 400 feet above the Pittsburg coal bed, but the shales and limestones break up under the weather so readily that there are no natural exposures. Long, deep cuts on the railroad east and west from Greensburg give this section:

	Feet	Inches
1. Limestone	2	6
2. Shale and limestone	119	0
3. Shale	40	0
4. Coal bed	3	4
5. Shale and flaggy sandstone	48	0
6. Limestone and shale	26	0
7. Shale	48	0
8. Pittsburg coal bed:		

	Feet	Inches	Feet	Inches
Coal and shale	2	6 to	5	4
Shale	9	0 to	18	0
Clay and coal, roof	0	3 to	5	8
Clay	0	6 to	3	0
Coal	6	6 to	7	8

The main division of the Pittsburg shows comparatively little variation on the west side, being usually 8 feet, but the changes in the roof are abrupt. The little coal above at the top of the horizon is thoroughly persistent, its blossom having been observed at many places within the basin. There seems to be no trace of the Redstone, for its place is well exposed. The coal bed, Number 4, is equally persistent, but is fully shown only along the railroad, where it is a double bed with from 16 to 30 inches of coal. It may be at the Upper Sewickley horizon, but its place is uncertain. Limestone is present in large proportion and in this respect the section differs greatly from that at a few miles east in the Blairsville-Connellsville and west in the Lisbon Irwin basin.†

The Lisbon-Irwin basin.—This lies west from the Saltsburg-Fayette anticline and extends westwardly to the Waynesburg fold. A small area

* J. J. Stevenson: (K 2), pp. 134, 135, 136, 144, 146, 147, 153, 154, 155, 156, 179, 180, 191. The writer is under obligation to Messrs W. Beeson, A. D. Ewing, and J. V. Thompson of Uniontown, Pennsylvania, for records of shafts and borings.

† J. J. Stevenson: (K 2), 272, 298, 299, 300.

of Monongahela, known as Elders ridge, and north from the Kiskiminetis river along the Armstrong-Indiana border, was studied by Mr W. G. Platt and, 25 years later, by Mr R. W. Stone. Another small area remains in Westmoreland at 1 mile and the continuous body is reached at 7 miles south from the Kiskiminetis. The first clear section is at the Youghiogheny shaft near Irwin, 20 miles south from Elders ridge; at somewhat more than 4 miles north is a boring, and at 4 miles farther north is another, very near the end of the continuous area. These may be compared as follows:

	Feet	Inches	Feet	Inches	Feet	Inches
1. Uniontown coal bed........	3	0	0	11	0	5
2. Shale, limestone, sandstone.	106	0	72	7	50	8
3. Coal bed	1 to 3	0	4	9	1	3
4. Shale, limestone, sandstone.	50	0	67	6	70	0
5. Pittsburg coal bed.........	11	2	15	6	Not measured	

Along the Pennsylvania railroad the Uniontown coal bed is about 160 feet above the Pittsburg and is above its limestone. In the first section it is about 60 feet below the Waynesburg, which is exposed on the hillside and about 3 feet thick. The Benwood limestone is 15 feet thick and 35 feet below the Uniontown limestone, so that it represents the upper part of the mass. A hard sandstone, 25 feet thick, rests on the middle coal bed along the railroad, while at 8 to 11 feet below that coal is a limestone; this condition suggests reference of the coal bed to the Lower Sewickley. The interval from the Uniontown to the Pittsburg decreases northwardly, being 158, 145, and 122 feet in the measurements given, while one intermediate between the last two shows 131. The coal beds of the section are present in Elders ridge, where they are 98 and 35 feet above the Pittsburg. An intermediate observation shows the lower bed at 65 feet above the Pittsburg, marking the renewed decrease in that direction. No higher coal is recorded in northern Westmoreland, where a record gives the overlying beds for 85 feet; the highest is a limestone, 7 feet 6 inches, evidently the same with that seen in Elders ridge at 83 feet above the Uniontown. The Fishpot and Uniontown limestones disappear northwardly, only the Benwood persisting in Elders ridge.

The Pittsburg retains its complex structure along the Pennsylvania railroad, where one often finds the "rider" coal of this, as in the Greensburg basin. In the Youghiogheny shaft this little coal is distributed in fragments throughout 2 feet of sandstone. The roof division is as variable here as elsewhere; at one pit it is 7 feet 4 inches thick, in nine layers, with, in all, 3 feet 5 inches of coal, but in another less than a

mile away it is 2 feet 1 inch thick and with but 2 inches of slate. The main division is very uniform, though often cut out badly by descent of the sandstone roof, and so sometimes distorted by clay-veins.

Southwestwardly the limestones increase as rapidly as in the Blairsville basin, for within a few miles the Benwood limestone is about 80 feet thick, with, directly under it, a richly carbonaceous shale representing the Upper Sewickley. The Waynesburg coal bed is shown farther south, near the Youghiogheny, thick and 25 feet above 7 feet of Waynesburg limestone. The Benwood is 65 and the Fishpot is 20 feet thick on the Youghiogheny. The Upper Sewickley coal bed, directly under the Benwood, is 5 inches thick and separated by the thinly bedded Sewickley sandstone from the limestone below. The Redstone coal bed is 60 feet above the Pittsburg and its ferruginous limestone is 6 feet thick. Between the Youghiogheny and the Monongahela an imperfect measurement gave 260 feet as the interval from Waynesburg to Pittsburg. The Waynesburg, Uniontown, and Upper Sewickley are all very thin, but the Redstone is often 3 feet. The last bed is much cut by clay veins, which bear no relation to disturbances in coal beds above or below. Such clay veins are characteristic of the Redstone and explain its absence from many records and sections. In this space between the rivers the Fishpot and Redstone limestones become very irregular at and in many places are represented only by nodules.*

Passing over into Fayette county, one finds the intervals increasing rapidly, though showing some irregularity. Between the Youghiogheny and the Monongahela, all members of the section except the Lower Sewickley coal bed are exposed frequently. The Waynesburg coal bed is sometimes 4 feet thick, the Upper Sewickley is from 3 inches to 30 inches thick, and the Redstone 3 to 4 feet, but the Little Waynesburg and the Uniontown are very thin. The limestones are important, the Benwood occasionally becoming 90 and the Fishpot 35 feet thick. The interval from Waynesburg to Pittsburg is 330 feet in Franklin township, where the Upper Sewickley is 118 feet above the latter bed. The Redstone coal bed is 25 to 40 feet above the Pittsburg and the Redstone limestone is somewhat indefinite. Near Brownsville, on the Monongahela, the Waynesburg is 345 to 360 feet above the Pittsburg and the Upper Sewickley is only 6 inches thick. In this direction the Benwood limestone becomes broken by a sandstone which at Brownsville is 20 feet thick.

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* J. J. Stevenson: (K 2), pp. 329, 335, 336, 339, 351, 352, 353, 361, 362, 363, 364. R. W. Stone: U. S. Geol. Survey folios, Elders ridge, p. 6.

Important mining operations in German and Redstone townships have led to making many shafts and borings, which exhibit conditions unsuspected from the surface exposures. Four of these from a small area may be compared.

I, Brier Hill shaft; II, Hibbs farm boring; III, Edenton shaft; IV, Lambert shaft.

	I	II	III	IV
	Feet	Feet	Feet	Feet
1. Waynesburg coal	5.3	7	6	8
2. Sandstone fireclay	14		23	33
3. Little Waynesburg coal...	3.5		4	0.2
4. Waynesburg limestone....	10.6		3	31
5. Interval	47.5	69	55	4
6. Uniontown coal bed......	4.2		2	2
7. Interval	7.8		28	2
8. Uniontown limestone	8.8	8		
9. Interval	7.9	23	120	159
10. Benwood limestone	121.2	136		
11. Interval	2.3	2	5	0
12. Upper Sewickley coal.....	3.4	1	0.8	Trace
13. Sandstone, shale	36.1	28	38	27
14. Lower Sewickley coal.....	0.0	..	..	2
15. Interval	0.0	..	..	3
16. Fishpot limestone........	24.3	18	21	18
17. Interval	21.4		19	21
18. Redstone coal	0.0		1	1
19. Interval	0.0	51	3	0
20. Redstone limestone	16.0		12	15
21. Interval	0.0			23
22. Pittsburg coal	..	..		
Coal and shale...........	7.8	3	45	2.6
Shale, fireclay, black shale	23.7	22		20.6
Main coal	7.0	7	7	7

The interval from Waynesburg to Pittsburg varies between 360 and 380 feet. The Benwood and Uniontown limestones are continuous in the Lambert shaft, where the mass contains only 3 feet of sandstone, and they are almost continuous in the Brier Hill, where, however, there is a much greater amount of shale and sandstone. The Redstone and Fishpot limestones retain their importance. The interesting feature is the wide separation of the parts of the Pittsburg coal bed, recalling conditions already observed in the Potomac, Salisbury, and Connellsville areas. The intervening 22 feet in the Hibbs boring is filled with carbonaceous shale, but in the other records a thin sandstone is reported. The interval from the Upper Sewickley to the Pittsburg main coal is from 139 to 112 feet, and the Sewickley sandstone is sometimes only a

sandy shale. Farther south, in German township, the interval is only 104 feet and the top part of the Pittsburg is represented by 8 feet of black shale, with 2 inches of coal in the lower part at 8 feet above the roof division. There also the Waynesburg coal is 102 feet above the Uniontown and 42 feet above the Waynesburg limestone. The Waynesburg coal bed, in numerous layers, is 7 feet 2 inches thick, but the Little Waynesburg and the Uniontown are thin, only 30 inches each. Still farther south the Sewickley sandstone decreases and the interval between Upper Sewickley coal bed and the Fishpot limestone diminishes, until near the last exposure the coal and limestone are almost in contact, the former at only 64 feet above the Pittsburg. There one is on the extreme eastern edge of the basin, practically on top of the fold. The Sewickley and Redstone coal beds are 5 and 4 feet respectively, the latter separated from the Pittsburg by 25 feet of sandstone; but the Fishpot limestone is still important, being 10 feet thick.

On the opposite side of the Monongahela, in Greene county, one is on the west side of the basin and there is less variation in the section. At about 12 miles north from the West Virginia line the Waynesburg is 90 to 95 feet above the Uniontown, which is double, its benches separated by 10 feet of sandstone. The Benwood limestone, resting on the Upper Sewickley, is 76 feet thick and separated by 30 feet of sandstone from the Uniontown limestone above. The Sewickley sandstone is 40 feet thick and the Waynesburg coal bed is 370 feet above the Pittsburg. Southward the section changes little, except that the Benwood limestone becomes thinner, its lower portion is replaced by sandstone, and the interval from Upper Sewickley to the Fishpot diminishes. The Redstone coal bed, 36 to 54 feet above the Pittsburg, is almost invariably accompanied by its limestone. The interval between Waynesburg and Pittsburg is 390 feet at the last complete exposure near the West Virginia line.*

The Waynesburg basin.—In this basin, between the Waynesburg and Bradys Bend (Washington) anticlines, detached areas remain in Allegheny county north from the Monongahela river, but beyond that stream the area is continuous southwestwardly into West Virginia.

In southern Plum township of Allegheny, about 10 miles west from the most northerly bore-hole in Westmoreland county, the hills rise to nearly 200 feet above the Pittsburg coal bed, but show nothing, aside from shales and sandstones, except a limestone, 8 to 10 feet thick and 70 feet above the coal. This may be some portion of the Benwood. Four

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* J. J. Stevenson: Greene and Washington (K), pp. 92, 94, 97, 98, 116, 118, 123, 134, 135; (K 2), pp. 204, 207, 208, 209, 210, 213, 215, 216, 233, 238, 239, 240, 241, 250.

miles southward a limestone 5 to 7 feet thick was seen 150 feet above the coal, and at 2 miles farther south it is 170 feet. It yields a dark but very strong lime and underlies a flaggy sandstone. Stevenson took it to be the Waynesburg limestone, but it is more likely to be the Uniontown, as the other does not extend so far north, and the overlying sandstone may be the Waynesburg in the Dunkard formation. Sandstone or sandy shale overlies the Pittsburg coal and extends upward 40 feet to a black shale holding some coal. No other exposure was seen and the Benwood limestone if present must be very thin; but that limestone is not less than 60 feet thick at 10 miles farther south, where the Waynesburg coal bed is 250 feet above the Pittsburg. At 8 miles west from the Monongahela river, in Snowden township, the Waynesburg coal bed, resting on the yellow Uniontown limestone, is 250 feet above the Pittsburg and the Benwood limestone, in many layers separated by shale, is 70 feet thick.*

Passing over into Union township of Washington county, one finds the intervals increasing, for at 6 or 7 miles from the last locality the Waynesburg coal bed is 55 to 60 feet above the Uniontown and the Waynesburg limestone is not present. The Benwood limestone, 60 feet thick, is very largely calcareous shale and the Fishpot seems to be wanting, but the Redstone makes its appearance, one foot thick and 6 feet below its coal bed, which is 50 feet above the Pittsburg. Sandstone fills the interval below the limestone. Three miles farther southwest the Fishpot is seen, 5 feet thick, and the Lower Sewickley horizon is marked by 2 feet of black shale separated by 35 feet of Sewickley sandstone from the Benwood limestone, of which 50 feet were seen. The Redstone limestone has increased to 3 feet. The Waynesburg coal bed is 50 to 55 feet above the Uniontown, which is almost in contact with its yellow limestone, 15 feet thick. Nine miles west, in Peters township, the Waynesburg is 175 feet above the Redstone, or barely 225 feet above the Pittsburg. The Uniontown coal bed is persistent in this region and seems to be about 3 feet thick, though not often yielding good coal. The Redstone coal bed is from 3 to 4 feet thick and sometimes has a limestone roof and floor. Southwardly the section shows comparatively little change, except in increasing intervals and in the appearance of the Waynesburg limestone. The Little Waynesburg coal bed is apparently wanting and the Sewickley horizons show coal only occasionally. Combining measurements by Doctor White one has:

* J. J. Stevenson: (K), p. 303; (K 2), pp. 375, 385, 388, 390.

	Feet	Feet
1. Waynesburg coal bed	5 to	8
2. Interval		30
3. Waynesburg limestone		Thin
4. Interval		66
5. Uniontown coal bed		3
6. Uniontown limestone	8 to	12
7. Shale and sandstone		28
8. Benwood limestone		80
9. Shale		5
10. Upper Sewickley coal bed	2 to	3
11. Sewickley sandstone	35 to	40
12. Fishpot limestone	25 to	30
13. Shale		25
14. Redstone coal bed		2
15. Pittsburg sandstone		40
16. Pittsburg coal bed	7 to	8

and near the Greene County border the Waynesburg is 362 feet above the Pittsburg.

In Morgan and Jefferson townships of Greene county the Waynesburg is triple to quadruple, varying in thickness from 6 to 12 feet, with from 4 to 7 feet of rather inferior coal, and is nearly 40 feet above its limestone, 6 to 8 feet thick. The Uniontown coal bed becomes irregular and is almost directly in contact with its limestone. About 40 feet of sandstone separate the latter from the Benwood, which, including much calcareous shale, is about 80 feet thick. The Sewickley sandstone and Fishpot limestone retain their importance, but the Redstone coal and limestone become indefinite. Farther southwest the Monongahela quickly passes under cover and the information from oil records is very imperfect. A record near the West Virginia line reported by Doctor White gives 345 feet as the interval between Waynesburg and Pittsburg, with a trace of the Upper Sewickley at 95 feet above the latter bed.*

The Western basins in Pennsylvania.—Petty areas of the Pittsburg coal bed, widely separated, remain in Allegheny county north from the Ohio river. The cover rarely exceeds 30 feet and is the massive Pittsburg sandstone. Even near Butler County line the bed retains its characteristic structure, showing:

	Feet	Inches		Feet	Inches
Coal and shale	3	3	to	6	6
Clay	1	2	to	1	4
Main coal	4	10	to	5	5

* J. J. Stevenson: (K), pp. 136, 140, 141, 143, 210, 211, 212, 221, 222, 223, 224, 225, 227, 228, 303.

I. C. White: (K), pp. 180, 201, 203, 215. Geology of West Virginia, vol. ia, p. 122.

An imperfect section south from the Ohio, about one mile from Pittsburg, notes a coal blossom at 70 feet above the Pittsburg coal bed and underlying one foot of ferruginous limestone. Sandstone and shale fill the well exposed interval to the Pittsburg, and there is no other limestone in 140 feet above the thin coal blossom. At about 8 miles south from Pittsburg and very near the line of Washington county, a section is:

	Feet	Inches
1. Limestone [Uniontown]	2	6
2. Shale, sandstone, concealed	49	0
3. Benwood limestone	40	0
4. Clay	1	0
5. Black shale [Upper Sewickley coal bed]	1	6
6. Shale, sandstone [Sewickley]	30	0
7. Black shale [Lower Sewickley coal bed]	1	0
8. Limestone, shale [Fishpot]	21	0
9. Shale	50	0
10. Pittsburg coal bed	11	8

At a mile north from this locality only sandstone and shale appear in 93 feet above the Pittsburg coal, so that the Benwood and Fishpot limestones enter the section abruptly. The thin limestone seen near Pittsburg at 70 feet above the Pittsburg evidently represents the Benwood, and its underlying coal is at the Upper Sewickley horizon. The highest limestone in this southern section, 193 feet above the Pittsburg, is probably the Uniontown and is very near the place of the Waynesburg coal bed. Ten miles northwest the Pittsburg coal bed is only 6 feet 3 inches in all and the Benwood limestone at 100 feet higher is 25 feet thick. The Fishpot at 60 and the Redstone at 30 feet above the Pittsburg are clearly present.

Crossing over into the northwest corner of Washington county, one finds a little area in which the Pittsburg coal bed is quite thin, 4 feet to 5 feet 2 inches, with nodular limestones representing the Redstone and Fishpot at 20 and 40 feet above it. The limestones are irregular north from the Pennsylvania railroad as well as in the northwest corner of the county. Limestones were seen on that railroad just west from the Allegheny line at 35 to 48, 60 to 73, and 130 to 143 feet above the Pittsburg, but they are irregular. At a mile south from the railroad the limestones appear abruptly, the thick Benwood is at 65 feet above the Pittsburg and 20 feet above the Lower Sewickley coal bed, while the Fishpot is 15 feet thick and 20 feet above the Pittsburg coal.

The section varies much in northern Washington and it must be followed in detail from the West Virginia line eastward across Jefferson,

Cross Creek, Mount Pleasant, Cecil, and Allen townships, a distance of about 25 miles.

At Eldersville, in the northern part of Jefferson, the measurement is:

	Feet
1. Washington coal bed	5
2. Interval	85
3. Limestone	1
4. Concealed	100
5. Sandstone	30
6. Pittsburg coal bed	5

The Washington coal bed, the great bed of the Dunkard formation, is 216 feet above the Pittsburg, and at 2 miles away it is 50 feet above the Waynesburg, making the interval from the latter bed to the Pittsburg only 166 feet. Three miles farther east, in western Smith township, the Uniontown limestone, bright yellow and thin, is 15 feet below the Waynesburg coal bed, but near Eldersville the coal and limestone are almost in contact. The Benwood is thin and in two layers, together not more than 10 feet. The Pittsburg coal, as in the more northerly townships, occasionally becomes block or even cannel. In northern Cross Creek, the Monongahela is buried under Dunkard, but in the southern part of that township the intervals are greater, for the Waynesburg is 90 feet below the Washington and 200 feet above the Pittsburg, the increase in the latter interval being in the upper part of the section, as the Waynesburg is now 50 feet above the Uniontown limestone, on which rests the Uniontown coal bed. No trace of the Waynesburg limestone is here. In the extreme southern part of the township the interval is 55 feet and the yellow Uniontown limestone is 8 feet thick.

An exposure in northwest Mount Pleasant shows the Waynesburg coal bed 3 feet thick and 20 feet above the Uniontown coal bed, which is separated by 2 feet of clay from its bright yellow limestone, 6 feet thick. At a little way farther north, in western Smith, the interval between the Waynesburg coal and the Uniontown limestone is but 15 feet. At Hickory, in Mount Pleasant, Doctor White made a direct measurement, giving the interval between Waynesburg and Pittsburg as 235 feet, showing that this interval increases southeastwardly as well as southwardly. In northern Cecil the Waynesburg is 210 feet above the Pittsburg only about 3 miles from the locality where the Uniontown limestone is 193 feet. There is no Waynesburg limestone anywhere along this line until one reaches the western part of Peters township, near the Monongahela river, where it is 12 feet below the coal bed.

In the next tier of townships southward exposures are very poor, as the soft calcareous rocks, there predominating, have yielded readily and the shaft records near Washington, 10 miles south from the Cecil line, are the only trustworthy sections. Near the Cecil line the Waynesburg is 230 feet above the Pittsburg, but at Washington a record shows that the interval has increased to 274 feet. There the Waynesburg is but 8 inches thick, and all of the other coal beds are wanting to the Pittsburg. A shaft north from Washington has 3 feet of coal at 21 feet above the Pittsburg and the Uniontown is present at 45 feet below the Waynesburg. The limestones are of noteworthy thickness. Near Washington the Fishpot is at 70 feet above the Pittsburg, and the Benwood is apparently continuous with the Uniontown and Waynesburg in one shalt, where 170 feet of limestone and shale are reported, beginning at 11 feet below the Waynesburg coal bed. The imperfect surface exposures show that the record is probably not incorrect. About midway in this mass salt water was found in a white limestone.

Westward the Monongahela is under deep cover for several miles until in Hopewell and Donegal townships one reaches the deep valleys of Brush run and Buffalo creek. There the Waynesburg is exposed, always very poor and, including the clay partings, varying from 2 feet 6 inches to almost 7 feet. The Waynesburg limestone makes its appearance on Brush run, where it is nodular and 25 feet below the coal; but farther south on Buffalo creek it is a solid bed 3 feet thick, with the Little Waynesburg at 13 feet above it. On these streams the Uniontown coal bed is 40 to 65 feet below the Waynesburg and practically rests on the right yellow Uniontown limestone, which is 12 feet thick at one place. In Independence township, north from Donegal along the West Virginia line, Cross creek cuts down to the Pittsburg coal bed. On that stream the Uniontown limestone is 96 feet below the Washington coal bed, 45 feet more than at Eldersville, 5 miles north. It is 6 feet thick and 15 feet above the Benwood limestone, of which 50 feet were seen. The Waynesburg and Uniontown coal beds are very thin, but the Pittsburg has increased southward in the interval from Eldersville, so that it is 8 feet.

Southward in Washington and Greene counties the Monongahela becomes buried more and more deeply under the Dunkard. Little information can be gleaned from well records, for they are mostly incomplete. Those which are available show that in Greene county the Waynesburg, one Sewickley, and the Pittsburg are the persistent coal beds. Two records in northern Greene give the interval from Waynesburg to Pitts-

burg as 302 to 306 feet; another, father east, shows 348, while along the West Virginia border the interval varies from 348 to 362 feet.*

THE NORTHERN PANHANDLE OF WEST VIRGINIA

Passing over into that portion of West Virginia which lies between the Pennsylvania line and the Ohio river, one finds the Pittsburg coal bed mined at Lazearsville on the Ohio river, in Brooke county, about 20 miles north from Wheeling and 5 miles south from Steubenville, Ohio, but it certainly extends in patches for several miles farther north. The full section must be present on Buffalo creek in this county, since at the Pennsylvania line the Pittsburg coal bed is below the bed of the stream. Farther south along the Ohio some sections are available in the vicinity of Wheeling. Two of them, one at Wheeling and the other between 3 and 5 miles east from that city, give:

	Feet	Inches	Feet	Inches
1. Sandstone	..	..	5	0
2. Limestone	..	..	0	10
3. Shale	..	..	2	0
4. Waynesburg coal bed	..	..	2 to 3	0
5. Clay, sandy shale	..	..	38	0
6. Uniontown coal bed	0	10	0	0
7. Shale, thin limestone on top	33	0	41	0
8. Alternating limestone and shale	115	0	103	0
9. Coal bed	1	2		
10. Fireclay, thin sandstone	6	4	3	0
11. Coal and shale	1	0		
12. Clay and sandstone	14	0	17	0
13. Coal and shale	1	8	3	6
14. Limestone and shale	24	0		
15. Coal and shale	1	0	56	0
16. Limestone and shale	20	0		
17. Shale	6	0	5	0
18. Pittsburg coal bed	7	11	6	8

The Waynesburg is identified clearly, the overlying limestone characterizes the Cassville shales of the Dunkard in much of western Washington county, and the Uniontown limestone is present, though thin, while higher in the hill appear the coals of the Dunkard in proper succession. Doctor White finds this bed at Wheeling 2 feet thick and 256 feet above the Pittsburg; the interval at 5 miles east is 266 feet. The Uniontown coal bed is not shown in the second section, but it

* J. J. Stevenson: (K), pp. 227, 228, 230, 231, 238, 248, 249, 258, 259, 260, 270, 274, 275, 277, 280, 287, 289, 292, 308, 317, 322.

I. C. White: (K), p. 268; (Q), p. 23. Geology of West Virginia, ia, pp. 121, 122, 126, 127, 128, 130, 132, 281, 282, 283, 284, 285, 293, 294.

was seen at Wheeling. Number 8 is the Benwood limestone and is made up of alternating layers of shale and limestone 3 to 6 feet thick. The Sewickley horizon includes Numbers 9 to 14. In these sections the vertical thickness is about 24 feet, but Doctor White found the three Wheeling beds in a vertical space of 43 feet at another locality within the limits of that city. The bottom bed is the Lower Sewickley and rests on limestone which may be taken as the Fishpot; the upper two at Wheeling are equivalent to the single bed of the second section and to the Upper Sewickley of Pennsylvania, the Meigs Creek of Ohio. The section remains above the river to a mile below Benwood or five miles below Wheeling. At 12 miles below Wheeling, near Moundsville, Doctor White obtained measurements showing the Waynesburg coal bed 3 feet thick and 265 feet above the Pittsburg. The Uniontown limestone is 2 feet and separated by sandstone from the great Benwood limestone. At 25 feet below the last is a thin coal bed, 44 feet above the Pittsburg, which is at the place of the Lower Sewickley. The place of the Uniontown coal bed is concealed. At about 12 miles south from Moundsville Mr J. E. Barnes made borings with diamond drill which show a notable increase in thickness, especially in the upper part of the section.

	Feet	In.	Feet	In.	Feet	In.	Feet	In
Waynesburg coal bed......	2	0						
Interval....................			77	0				
Uniontown coal bed..........	207	0	0	9				
Interval			146	3				
Sewickley coal bed..........	3	0	2	4	3	6	3	6
Interval			59	10			1	2
Redstone coal bed............	87	11	1	1	83	0	60	0
Interval			23	0			27	1
Pittsburg coal bed..........	5	5	5	11	7	9	5	7
Total	297	11	310	3	83		88	3

In the second section the interval from Waynesburg to Uniontown is an estimate, as the core begins below the upper bed. The Waynesburg is about 300 feet above the Pittsburg, but the interval from the Uniontown to the Pittsburg is almost the same as at Wheeling; the relations of the Upper Sewickley show equally small change. The limestone is still in notable quantity throughout the section. A new feature appears in the presence of red shale, unknown in the Monongahela of Pennsylvania and farther north in West Virginia. One of these borings shows four layers, in all 8 feet thick, between Waynesburg and Sewickley, the lowest at 60 feet above the latter coal bed; another shows six

layers, in all 18 feet 6 inches thick, the lowest at 70 feet, while a third shows 6 feet in 118 feet above the Upper Sewickley, the lowest being at 74 feet above that bed.*

OHIO

Passing over into Ohio, one finds the most northerly exposure at Knoxville, in Jefferson county, about 15 miles north from Steubenville, where Henry Newton obtained this section:

	Feet	Inches
1. Olive and red shale, with thin bands of buff limestone	76	0
2. Coal bed [Waynesburg]	1	6
3. Olive shale	108	0
4. Coal bed [Sewickley (?)]	2	6
5. Olive shale	30	0
6. Pittsburg coal bed	4	0

This is farther north than any locality in Pennsylvania giving measurements above the Pittsburg. Twelve miles southeast, at Eldersville, in Washington county of Pennsylvania, the interval, Waynesburg to Pittsburg, is 166 feet. Here the upper coal is 140 feet and is most probably the Waynesburg, with red shale of the Dunkard above it. All trace of limestone has disappeared and the lower coal bed is at a Sewickley horizon.

At 8 miles farther south, Stevenson found a thin coal bed at 65 feet above the Pittsburg underlying 50 feet of shale and flaggy sandstone, no trace of coal appearing. At a little way west both Professor Newberry and Professor Brown note a coal bed 29 to 34 feet above the Pittsburg with limestone above the lower bed and at one locality above the upper. The limestone and coal disappear farther west, near the edge of Harrison county, where the Waynesburg coal bed is 100 feet above the Upper Sewickley, which is 69 feet above the Pittsburg. Some thin limestone appears above the Upper Sewickley, but none below. The interval between Sewickley and Pittsburg increases within 3 miles southward to 81 feet, and in the lower 21 feet of that interval are two thin limestones and two thin coal beds. In the southern part of the county, near the Belmont border, the interval, Waynesburg to Upper Sewickley, increases to 160 feet and the Benwood limestone attains a thickness of 60 feet. The Upper Sewickley is 4 feet thick, with a thin coal bed 35 feet below it, just midway to the Pittsburg. This lower interval

* I. C. White: Catalogue of West Virginia University, 1883-1884, pp. 56, 60. Geology of West Virginia, vol. ii, pp. 131, 132, 133, 134, 135.
J. J. Stevenson: Manuscript notes.

has 50 feet of limestone. The interval from Waynesburg to Pittsburg along the western border of Jefferson county is 140, 171, 182, 209, and 235 feet, and at 4 miles east from the last is 245 feet, 10 miles north from Wheeling, where it is approximately 260 feet. The Waynesburg is Number 11 and the Upper Sewickley is Number 10 of Stevenson's Jefferson County report.

Professor Brown finds the Upper Sewickley (Meigs Creek) at 92 feet above the Pittsburg, on the Harrison county line. In Harrison, west from Jefferson, the generalized section shows:

	Feet	Inches
1. Waynesburg (11) coal bed..........	2	0
2. Mostly sandstone	91	0
3. [Upper Sewickley] (10) coal bed....	11	0
4. Sandstone	60 to 75	0
5. Coal bed [Redstone (?)]...........	2	6
6. Mostly limestone	15 to 30	0
7. Pittsburg coal bed.................	7 to 8	0

Here, as in Jefferson county, a coal bed (12) is at 50 feet above the Waynesburg. The Upper Sewickley, insignificant in most of Jefferson county, is an important bed, triple, the middle bench 4 feet 6 inches and the others 1 foot 2 inches. It averages about 90 feet above the Pittsburg, though at times decrease in the lower interval makes it less. The limestone above the Pittsburg is replaced by sandstone along the western outcrop. There are mere traces of the Benwood limestone, but at times a thin limestone appears below the Waynesburg coal bed which may represent the Uniontown. The Pittsburg coal bed in the main division varies from 4 to almost 6 feet and the coal is much more variable in quality. At some localities it is excellent, while at others it is decidedly inferior. The roof division is of uncertain occurrence, being absent from considerable areas. It is usually thin, little more than one foot, but it was measured 4 feet at one pit, where the whole thickness was not exposed.*

Returning to the Ohio river, one enters Belmont county, south from Jefferson and Harrison. At Bridgeport, opposite Wheeling, Stevenson found the Waynesburg (11) coal bed 245 feet above the Pittsburg by barometer, 3 feet 6 inches thick, 2 feet above a limestone and 188 feet above a thin coal bed, apparently the Lower Sewickley of the Wheeling section. Professor Brown saw the Redstone near by at 20 to 23 feet

* Jefferson county. J. S. Newberry: Ohio Geology, vol. iii, pp. 753, 763. J. J. Stevenson: Vol. iii, pp. 767, 773, 777. C. N. Brown: Vol. vi, p. 601.
Harrison county. J. J. Stevenson: Vol. iii, pp. 202, 215, 217.

above the Pittsburg, and the Upper Sewickley (8*c* of the Belmont report) is 3 feet thick at a little way back from the river.

Four miles south from Bridgeport, at Bellair, is Professor Brown's carefully leveled section:

	Feet	Inches
1. Coal bed	Blossom	
2. Interval	53	0
3. Coal bed [Waynesburg]	2	0
4. Shale and sandstone	18	0
5. Coal bed [Little Waynesburg]	Blossom	
6. Limestone [Waynesburg]	3	0
7. Concealed	5	0
8. Coal bed	Blossom	
9. Concealed	14	0
10. Coal bed	Blossom	
11. Shale, sandstone, concealed	103	0
12. Calcareous shale, limestone	24	6
13. Meigs creek [Upper Sewickley] coal bed	4	0
14. Sandy shale	14	0
15. Coal bed	0	8
16. Clay shale	6	0
17. Coal bed and shale [Lower Sewickley]	3	0
18. Limestone, shale, concealed	38	0
19. Coal bed [Redstone (?)]	2	0
20. Interval	17	0
21. Pittsburg coal bed	7	0

The Sewickley coals are in a vertical space of 28 feet and the top of the Upper Sewickley is 84 feet above the Pittsburg; at Wheeling this interval varies from 80 to 97 feet. The Waynesburg is 167 feet higher, and the blossom, Number 10, is at the place of the Uniontown coal bed.

The variations in the section between the Ohio river and the western outcrop have proved very perplexing and the sections have been interpreted differently by different observers. One must depend upon the measurements made by Professor Andrews, those by Stevenson being without value in certain portions of the county, where he clearly lost hold of the section. At Barnesville, 22 miles west from the Ohio river, Professor Andrews obtained a long section, which, condensed is:

	Feet	Inches
1. Shale	8	0
2. Coal bed	Blossom	
3. Clay	4	0
4. White limestone	1	0
5. Sandstone, clay, slate, concealed	38	0
6. Coal bed, Tunnel seam	2	0

	Feet	Inches
7. Shale, sandstone	24	6
8. Coal, slate, black slate, coal	6	9
9. Clay, limestone, shale	71	3
10. Cumberland [Meigs creek, Upper Sewickley] coal bed	6	7
11. Clay	3	0
12. Sandstone	35	0
13. Limestone, concealed	9	0
14. Coal bed	Blossom	
15. Clay, limestone	19	0
16. Coal bed	Blossom	
17. Clay, sandstone, shale	30	0
18. Pomeroy [Pittsburg] coal bed	4	4

Eastwardly from Barnesville the surface rises rapidly and the beds fall so that the highest portion of the section alone can be followed for 10 miles. A deep cut on the railroad summit several miles east from Barnesville shows the highest bed 2 feet thick and, near by, the Tunnel seam is represented by 2 feet of black shale containing some coal. It underlies yellow shale as at Barnesville and a thin coal below answers to Number 8 of the section. Near Belmont, 7 miles from Barnesville, the three coal beds are recognized, the intervals being approximately 40 and 30 feet, and just beyond Belmont the lowest coal bed is 27 feet above a limestone. At 3 miles south from this locality a coal bed is at 100 feet above the Tunnel seam and another at 40 feet below. The section remains perfectly clear along the railroad to Lewis mills, in Smith township, where the succession is:

	Feet	Inches
1. Black shale	10	0
2. Interval	33	0
3. Coal bed	Blossom	
4. Interval	53	0
5. Tunnel coal bed	4	6
6. Interval	37	0
7. Coal and partings	2	7
8. Interval	23	0
9. Limestone	4	0

The group is followed to this place from Belmont easily, as the road falls somewhat more rapidly than the beds; but there is a notable increase in the intervals. At Barnesville, from the bottom of the highest coal bed to that of the lowest, the interval is 76, but here it is 97 feet. These beds are present at 7 or 8 miles south from Lewis mills, where they are 5, 2, and 3 feet thick respectively and the intervals are 46 and 42,

the full interval being 93 feet. Eastward from Lewis mills, on the railroad, one descends rapidly in the section, and at Warnock a coal bed underlying 26 feet of sandstone is at 96 feet above the Upper Sewickley.

At Lewis mills the lowest coal bed underlies 23 feet of "sandrock with more or less of sandy shale." Three miles east from Warnock, Professor Andrews reports a coal bed at 174 feet above the Upper Sewickley, which would be very near the place of the highest coal bed at Lewis mills, if there be no change in the section. No measurement is available along the railroad, but there is one reported by Professor Andrews in Washington township, 8 miles south from Glencoe and about 3 miles east from one already given from the same township; this shows:

	Feet	Inches
1. Tunnel seam	Not measured	
2. Interval	47	6
3. Coal and shale	3	0
4. Interval	122	0
5. Cumberland [Upper Sewickley] coal bed	3	5

giving 172 feet as the interval from the Tunnel seam to the Upper Sewickley; so that the high bed at Glencoe is the Tunnel seam.

Passing Glencoe, one has the lower portion of the formation exposed repeatedly to Bellair, where the measurements by Professor Brown make the interval from Waynesburg to Upper Sewickley 165 feet. The correlations for the higher beds at Bellair, Lewis mills, and Barnesville, with the intervals, are:

	Feet	Feet	Feet
Waynesburg A			
Interval	53	53	43
Waynesburg (Tunnel)			
Interval	40	39	31
Uniontown			

The interval below the Waynesburg is to the bottom of the Uniontown coal bed. The Waynesburg A belongs to the Dunkard formation. At Bellair the Uniontown is 127 feet above the Upper Sewickley—at Glencoe, 96, and at Barnesville 71 feet. Between Glencoe and the river the interval between the Upper Sewickley and the Pittsburg varies in Professor Andrew's sections from 72 to 79 feet, while at Barnesville it is 96 feet, the increase being due to the appearance of a thick sandstone almost directly under the upper coal bed. The Lower Sewickley and the Redstone are still recognizable at Barnesville, but they are very thin. The interval from the Pittsburg to the Waynesburg (Tunnel)

coal decreases from 252 feet at Bellair to 202 feet at Barnesville, where the higher bed is 103 feet above the Upper Sewickley.

Stevenson's measurements in northern Belmont, beyond the central part of the county, are confirmatory of these conclusions. His section is:

	Feet	Inches
1. Coal bed [Waynesburg A]	2	0
2. Sandstone	40	0
3. Coal bed [Waynesburg]	1	3
4. Sandstones and thin limestones	95	0
5. Coal bed [Upper Sewickley]	4	6
6. Concealed	30	0
7. Coal bed [Lower Sewickley]	2	6
8. Fireclay	0	3
9. Mostly limestone	65	0
10. Shale and clay	3	0
11. Pittsburg coal bed seen	2	0

But this is very near the western limit of the Fishpot-Redstone limestone, for at a short distance toward the west a measurement shows the interval between Upper Sewickley and Pittsburg, 105 feet, filled almost wholly with sandstone, there being no trace of limestone. The Benwood limestone practically disappears within 11 miles west from the river, there being thence only a few irregular streaks and those quite argillaceous. The Upper Sewickley is usually triple, as in Harrison county, with a thick middle bench; sometimes, however, the other benches are wanting; the thickness varies from 4 feet 6 inches to nearly 9 feet. The Pittsburg bed becomes thinner toward the west, and on that outcrop does not always show the roof division.

In Guernsey county, west from Belmont, the limestones have practically disappeared, there being only 5 feet in 140 feet above the Pittsburg coal bed. The Upper Sewickley is single, underlies 30 feet of sandstone, and is from 100 to 112 feet above the Pittsburg. In the extreme southwest corner of the county, Professor Andrews's sections show no trace of either Uniontown or Waynesburg in 113 feet above the Upper Sewickley, which is 97 feet above the Pittsburg. These sections show red shale 25 and 19 feet at 30 and 82 feet above the Upper Sewickley. Followed westward, the Pittsburg is seen growing thinner and yielding poorer coal.*

The Pittsburg coal bed is present in southeastern Muskingum, on the Guernsey-Noble border, but is very irregular, 2 feet 5 inches to

* Belmont. E. B. Andrews: Vol. ii, pp. 547, 555, 556, 557, 563, 564, 569. J. J. Stevenson: Vol. iii, pp. 274, 280, 281. C. N. Brown: Vol. vi, pp. 613, 619

Guernsey. Andrews: Vol. ii, pp. 536, 537. Stevenson: Vol. iii, 225.

somewhat more than 5 feet thick. It underlies 27 feet of massive sandstone. The Upper Sewickley coal bed in the same area is triple, about 5 feet thick and 113 feet below the Waynesburg, which is coal and black shale 22 inches thick and underlies a coarse white sandstone. Professor Brown found the interval to the Uniontown 128 feet in one place, where the Upper Sewickley is less than 90 feet above the insignificant Pittsburg.

In Morgan county, south from Muskingum, the Pittsburg shows a ragged boundary. Along the western border it is wanting at the north, then reappears 2 feet thick and increases southwestwardly until, in the southwest township, it becomes 9 feet; but it disappears abruptly, so that in a well no trace of it was found and two beds of red shale 12 and 24 feet thick were found at 150 and 281 feet above the Ames limestone. The lower bed is at the place of the Pittsburg and underlies the Pittsburg sandstone, while the higher bed is at the place of that seen on the Guernsey-Noble border at 30 feet above the Upper Sewickley. Eastwardly the Pittsburg is equally variable and it disappears before the eastern boundary has been reached. A thin coal bed, almost midway between the Upper Sewickley and the Pittsburg, is reported at several places. The Upper Sewickley coal bed, 238 to 250 feet above the Ames limestone, is as variable as the Pittsburg, being important along the Muskingum border, but thinning and finally disappearing toward the southwest. In the central townships it rarely exceeds 2 feet 6 inches, while on the eastern side, where the Pittsburg is absent, it thickens to 4 feet. The interval to the first coal above the Upper Sewickley is given as 120 feet near the Muskingum border, but at the south, near the Athens line, it is from 96 to 115 feet. For the most part this bed is thin and it nowhere exceeds 2 feet. In Center township a coal at 156 feet above the Upper Sewickley may represent the Waynesburg; it is 100 feet below the Washington. The same bed is in Marion at 150 feet above the Upper Sewickley and 54 feet above the blossom of the Uniontown. Limestone beds are not thick, but they are numerous in the interval below the Uniontown, recalling the condition observed in eastern Belmont.*

Noble county, south from Guernsey, is east from Muskingum and Morgan. The Pittsburg coal bed, 92 feet below the Upper Sewickley (Meigs Creek), is present in the northeast township at a few miles southwest from Barnesville, in Belmont county. A mere trace of the

* Muskingum. E. B. Andrews: Vol. i, pp. 339, 340. C. N. Brown: Vol. v, pp. 1070, 1071.

Morgan. Andrews: Vol. i, pp. 294, 295, 296, 301, 302, 304, 305, 307, 309, 310, 312, 317. Brown: Vol. v, 1067, 1069. J. A. Bownocker: Bulletin 1, p. 136.

bed was seen at one place in the adjoining township, but elsewhere it seems to be wanting. Its horizon is exposed in most of the townships, and oil borings have been made in others where its place is below the surface. Its place is 92 to 102 feet below the Upper Sewickley and 140 to 160 feet above the Ames limestone. The Lower Sewickley is present in the northeast corner at 20 to 25 feet below the Upper, and in some other parts of the county traces of a lower bed were seen at 50 to 60 feet. Limestone in thin bands often occurs within 70 feet below the Lower Sewickley, and in the eastern townships the beds are 5 to 11 feet thick.

The Upper Sewickley is the important coal bed of Noble county and usually shows the triple structure. It is present in all of the townships and ordinarily is of workable thickness, though varying from 20 inches to 7 feet. It is best in the southern part, near the Washington border, where it is known as the Macksburg coal. Along the northern line it is 240 feet above the Ames limestone, but near the southern line that interval increases to 258 feet. In one of the eastern townships the upper division of the bed is replaced by a thin white limestone, which rests on the clay parting without any irregularity. The roof is a thin shale, underlying a sandstone sometimes 30 feet thick. In much of this county limestone is more abundant above the Upper Sewickley than in western Belmont, notably in some of the eastern townships, where it persists even to the southeast corner. Some sections show as much as 30 feet.

The Uniontown coal bed, 195 to 215 feet above the Pittsburg, is reported occasionally at 103 to 113 feet above the Upper Sewickley, the greatest interval being at the east on the Monroe border. It is usually very thin, but at one exposure near the Monroe line it is double, with 12 and 5 inches of coal, separated by 5 inches of clay. A bed about 50 feet higher and exceedingly thin is reported at a few localities and is very near the Waynesburg horizon. Red shale, 14 feet, was seen at 46 feet above the Upper Sewickley in a section near the Guernsey line. Elsewhere this horizon is concealed.*

Monroe county, south from Belmont, is east from Noble. In going eastward one is in the direction of increasing intervals and increasing limestones, so that the somewhat widely separated measurements seem at first to be irreconcilable.

It will be remembered that the Uniontown coal bed is persistent in southern Belmont county; it is thin along the Baltimore and Ohio

* E. B. Andrews: Vol. ii, pp. 511, 512, 513, 518, 519, 522, 523, 524, 526, 527.
C. N. Brown: Vol. v, pp. 1075, 1077, 1080, 1081.

railroad, but is better developed in Washington and York townships near the Monroe line. In Warren township at the west it is 71; in Wayne, 87; in Smith, 96, and in Washington 122 feet above the Upper Sewickley. In Wayne it is 74 feet above a peculiar magnesian limestone; farther east the interval varies from 75 to 80 feet, the increasing interval between Uniontown and Upper Sewickley being caused by increase in and below this limestone, the "Cement" of Professor Andrews. This relation may serve in working out the conditions in Monroe as well as to explain the increased interval between those coal beds along the westerly outcrop southwest from Belmont county. In Belmont the Waynesburg coal bed becomes insignificant south from the Baltimore and Ohio railroad and at most localities appears only as an insignificant blossom.

Along the western side of Monroe county, into which the section can be followed from Noble county, everything is simple. The Pittsburg seems to be wanting at all exposures, but it is reported very thin, in a well within Summit township. The Upper Sewickley is a double bed, 3 feet 8 inches to more than 6 feet, with a parting 4 inches to 2 feet 6 inches, varying at expense of the coal; the lower division is commonly thicker than the upper. The horizon of this bed soon passes below the surface at the north, but at the south it remains above drainage for fully 8 miles from the west line.

In passing from the western tier of townships, one crosses a space without clear exposures, beyond which the succession is distinct enough. A series of sections along Sunfish creek across Center, Adams, and Salem townships at 6 to 8 miles from the Belmont line makes the connection. In Center, Professor Andrews gives:

	Feet	Inches
1. Red shale, ore bearing	63	0
2. Concealed, elsewhere 20 feet of sandstone at base	51	0
3. Coal bed	0	6
4. Concealed	23	0
5. Coal bed	1	6
6. Shales	70	0
7. Coal bed	Blossom	
8. Interval	99	0
9. Coal bed	5	9

and he states that a very thin coal bed is at about 50 feet above Number 9. This lowest bed is complex, the structure being

Coal, 1 foot 8 inches; clay with plant impressions, 2 feet 8 inches; coal, 2 inches; clay, 5 inches; coal, 10 inches.

A "Cement" limestone is persistent at 70 to 80 feet below this coal. The interval to the coal bed, Number 7, is roundly 170 feet. The bottom coal bed and its magnesian limestone are shown along the creek into Adams township, where Professor Andrews gives another section, showing the red beds of Center and the three coal beds, 74 and 96 feet apart, the total interval being 170 feet, with the magnesian limestone at 85 feet below the bottom bed. The limestone goes under soon after entering Salem township, but the coals remain above, and at a mile from the Ohio river Professor Andrews finds the three beds as before, 70 and 100 feet apart, the middle one being 3 feet 6 inches, making the total interval 173 feet 6 inches. At the mouth of the creek, at Clarington, Doctor White's section shows the red beds on top, with the three coal beds 65 and 98 feet apart, the whole interval being 166 feet, and, according to Professor Andrews, the magnesian limestone was reached there in a shaft at 75 feet below the lowest coal bed.

All the conditions point to correlation of this lowest bed with the Uniontown. The relation to the magnesian limestone is that shown by the Uniontown in southern Belmont. At the mouth of Pike creek, in southern Belmont, the Uniontown is 55 feet below the Waynesburg and 179 feet below the Washington. It is about 100 feet below the Waynesburg A. Evidently the Waynesburg coal bed is wanting or so thin as to have no observed trace except in Center township, where, at 50 to 55 feet above the Uniontown coal bed, there is a bed of fireclay known as the "potters' bed," which sometimes carries a trace of coal, and in Perry township, where the record of an oil boring shows trace of coal at 240 feet above the Pittsburg. The Uniontown coal bed retains its peculiar structure to the Ohio river. It resembles the structure of the same bed in central West Virginia along the Baltimore and Ohio railroad.

The Uniontown coal bed is recognized southward in Greene and Perry townships, in each case triple, with the characteristic plant bed, but much reduced. Along the Ohio river the interval to the Washington increases, being 190 feet at Sardis and 191 at Baresville, both in the township south from Salem. This increase of interval is in accord with measurements in Tyler county of West Virginia and is evidenced by an intermediate measurement reported by Doctor White, which gives 125 feet as the interval between the lower coal beds. The Uniontown grows thinner southwardly along the Ohio, being only 2 feet at Baresville, while still farther south it seems to be wanting; for in a section by Professor Andrews its place is exposed at 188 feet below what certainly seems to be the Washington, but no trace of coal appears.

Red beds are represented scantily in Monroe county. One of 6 feet is at 36 feet below the Upper Sewickley in the southwest part of the county, and an oil record reports 13 feet at 100 feet above the Pittsburg in the southwest; but exposures are so incomplete throughout that no conclusion respecting distribution of these beds can be drawn.*

Returning to the western outcrop in Athens county, south from Morgan, one has Professor Lovejoy's generalized section for these two counties:

	Feet
1. Sandstone	60
2. Coal bed [Uniontown]	Blossom
3. Shale	10
4. Limestone	0 to 3
5. Shale	35
6. Limestone	0 to 10
7. Shale	15
8. Limestone	0 to 7
9. Shale	25
10. Limestone	0 to 12
11. Shale	10
12. Coal bed [Upper Sewickley, Meigs Creek]	—
13. Shale and sandstone	20
14. Limestone	0 to 12
15. Shale, limestone, or sandstone	10 to 75
16. Pittsburg coal bed	—

The average intervals are, Number 2, 190, and Number 12, 95 feet above the Pittsburg. The great sandstone on top is evidently the 200-foot conglomerate of Professor Andrews. The Pittsburg coal bed is as irregular in Athens as in Morgan. It is 4 feet to 9 feet 6 inches in the northeastern townships, usually absent in the central, and thin in the southern portions. At one locality, where the overlying sandstone is replaced by shale, thin coals are at 15 and 67 feet above the main coal bed, the former underlying 14 feet of red shale; at another exposure 9 feet of red shale overlie the sandstone.

The Upper Sewickley is absent from many townships, but occasionally on the eastern (Washington) border it is 6 feet thick. The interval to the Pittsburg is said to vary from 95 to 128 feet, this variation appearing to depend much upon the thickness of the sandstone deposit. Notwithstanding the variations in this interval, that between the Pittsburg and Uniontown (Hobson of Andrews) has 185 and 195 as its extremes.

* E. B. Andrews: Vol. ii, pp. 571, 586.
J. A. Bownocker: Bulletin i, pp. 196, 210, 212, 213.
I. C. White: Catalogue of West Virginia University for 1883-1884, pp. 61 to 65.

The Uniontown is wholly unimportant. The limestones are variable to the last degree.*

Washington county, south from Noble and Monroe, is east from Morgan and Athens. On the western border the Uniontown (Hobson) coal bed is at 104, 89, and 105 feet above the Upper Sewickley (Meigs Creek, Cumberland) coal bed and in three townships there is a very thin coal bed at 140, 150, 135, and 147 feet above the Upper Sewickley, which is at the place of the Waynesburg and underlies a coarse sandstone, evidently the 240-foot conglomerate of Andrews. The Uniontown is usually a double bed, frequently underlying plant-bearing shales, apparently equivalent to the bed's upper parting in Monroe. As in other counties, it rests on clay and limestone, and generally one finds a sandstone at a few feet above it, though at times this is replaced by shale. In the northwestern part of the county a "limestone group," at most 30 feet thick, inclusive of shale, is at 11 to 18 feet above the Upper Sewickley; but this disappears eastwardly, so that in Noble, as in most of Washington, it is replaced by sandstone. It seems to disappear in southwestward direction also, and no trace of it remains in Decatur township at the southwest corner.

The section can be followed readily across the greater part of Washington county almost to the Ohio river, as the Cowrun anticline brings up the lower part of the formation. Along the northern border, in Salem, Liberty, and Ludlow townships, the Uniontown (Hobson) coal bed is about 95 feet above the Upper Sewickley, which is 85 to 100 feet above the Pittsburg. The Uniontown is very thin, apparently seldom more than one foot thick. Mr Minshall's section in Liberty shows it resting on its clay and limestone, with a coarse sandstone at 6 feet above. No trace of the sandstone at "240 feet" remains here, and the sandstone overlying the Uniontown is coarser than at any other locality away from the Ohio river in this county, though in other counties it is noted as very coarse. In this section the Waynesburg A is 100 and the Washington 160 feet above the Uniontown, just as in Pleasants county of West Virginia, 8 or 9 miles east of south. The interval below the Uniontown is filled mostly by shales and sandstone and the sandstone at one to 6 feet above the Upper Sewickley sometimes becomes 50 feet thick. Occasionally, however, the upper part of that sandstone is replaced by red shale, 52 and 27 feet being recorded at 27 and 18 feet above the coal bed. At one locality 10 feet of shale and limestone overlie the upper

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* E. B. Andrews: Vol. i, pp. 270, 273, 274, 282, 286, 287.
C. N. Brown: Vol. v, pp. 1061, 1062, 1063.
E. M. Lovejoy: Vol. vi, pp. 629, 646.

red bed. The Upper Sewickley is from 5 to 6 feet thick, double, with a clay parting varying at expense of the coal, from 2 inches to 2 feet thick. This bed yields a good fuel, though somewhat high in ash. The Pittsburg coal bed is thin, from 1 foot 2 inches to 2 feet 10 inches, occasionally cannel. It underlies alternating limestone and shale, about 10 feet, and a similar "group" is at 20 feet higher. The Pittsburg is known as the "limestone" and the Upper Sewickley as the "sandstone" vein.

The section is equally clear in the tier of townships next south. The Uniontown is 95 feet above the Upper Sewickley in Muskingum, but only 82 feet in Lawrence, 8 miles east. It overlies its clay and limestone and varies in thickness from 2 feet 4 inches to 4 feet 3 inches. At the west it is double, but in Lawrence it is broken into six layers of coal and shale and a variable sandstone is above it. The bed seems to be irregular farther east in Independence township, where it is shown in one section, but is wanting in another, where, however, its overlying sandstone is shown at somewhat less than 100 feet above the Upper Sewickley. This sandstone is especially well marked along the river townships and is rather uncertain at the west, where the higher sandstone is present. For the most part the sandstone overlying the Upper Sewickley is coarse and massive, sometimes pebbly and occasionally 60 feet thick. In Lawrence township, 7 or 8 miles northeast from the city of Marietta, Professor Andrews found, at 42 feet above the Upper Sewickley, a coal bed varying from a mere trace to 4 feet 6 inches. It seems to be confined to a very small area, for no trace of it appears anywhere else in the sections, though Andrews says that he has observed some traces of it in other townships. The Upper Sewickley becomes thin and uncertain in the eastern townships, occasionally 3 feet thick, but usually much less and often wanting. The Pittsburg, 85 to 91 feet lower, is wholly unimportant, usually little more than a trace, but the limestone above it persists. These conditions closely resemble those observed in Tyler and Pleasants of West Virginia.

East from the Cowrun anticline the beds fall rapidly to the east and details are lacking in the river townships, Grandview, Independence, and Newport. Doctor White's long section in southern Grandview, about 7 miles below the Monroe line, shows what appears to be the Washington of the Dunkard at 150 above the river, so that the place of the Uniontown is not reached; but at 4 miles lower down the Uniontown is reached, 3 feet thick, 10 feet under a massive sandstone and 161 feet under the Washington coal bed. Two miles farther down, in Newport township,

this sandstone is very coarse, sometimes thickening so as to fill the whole interval to the place of the Waynesburg, while the underlying Uniontown coal bed is 3 feet thick and double, as in Lawrence township 3 or 4 miles west north of west. At 3 or 4 miles farther the Cowrun anticline or "oil break" is reached. The Pittsburg and Upper Sewickley seem to be wanting.

On the westerly side of the fold exposures are poor and information is wanting. An oil boring at Marietta shows the Pittsburg and Upper Sewickley absent, and the same is true at Parkersburg, West Virginia, about 10 miles below Marietta. The record at Marietta begins about 220 feet above the place of the Pittsburg, and that at Parkersburg at about 400 feet above the same horizon, but no evidence that the Uniontown is present appears in either record. No trace of the sandstone overlying the Uniontown coal bed is present in the Parkersburg well, opposite Belpre, Ohio, but the higher sand, about 240 feet above the Pittsburg, is present, 15 feet thick. Four or 5 miles farther down it comes up from the river bed as a coarse rock, and thence for many miles is an important member of the section.

The sections published are for the most part imperfect, as exposures are bad, so that one may not speak with certainty respecting distribution of red shale. On the western border a bed 24 feet thick is shown in one section at 30 feet above the Upper Sewickley; in Adams township the same horizon shows 52 feet at 27 feet, and in Ludlow 27 feet at 18 feet above the same coal bed. In the southern part a record at Marietta shows a great mass beginning in the Conemaugh and continuing upward into the Monongahela for at least 50 feet, and other beds are at 85 and 120 feet higher, the lower one apparently at the horizon above the Upper Sewickley.*

Meigs county is south from Athens and borders the Ohio river. The Monongahela is only on the eastern half of the county. From the northeast corner of Washington county the Ohio river flows almost west of southwest, so that when Meigs county is reached one has come near to the western outcrop of the Monongahela; but from the Athens line the river flows almost southward for more than 20 miles and for the greater part of the distance one seldom sees anything below the lowest beds of the Dunkard. At Antiquity, on the river, 16 miles south from the Athens line, is a measurement by Doctor White:

* E. B. Andrews: Vol. ii, pp. 460, 461, 462, 463, 471, 472, 475, 476, 478, 479, 482, 483, 496, 499, 503, 504, 505, 506, 507.

E. Orton: Vol. vii, pp. 399, 400.

J. A. Bownocker: Bull. 1, pp. 136, 142.

I. C. White: Catalogue of West Virginia University, 1883-1884, pp. 73, 74, 75, 76.

	Feet	Inches
1. Red and variegated shale	30	0
2. Massive sandstone	20	0
3. Red shale and concealed	30	0
4. Coarse massive pebbly sandstone	40	0
5. Sandy shale	10	0
6. Concealed	90	0
7. Massive sandstone	15	0
8. Concealed in shaft	125	0
9. Pittsburg coal bed	5	8

	Feet	Inches
Coal	2	6
Clay	0	2
Coal	3	0

The coarse pebbly sandstone is that which made its appearance in the Ohio river bed at the southern point of Washington county and is evidently that noted in the Parkersburg record. Where it first appears it is 25 feet under a coal blossom. Near Long Bottom, in Meigs county, 25 miles below Parkersburg, a coal blossom is said to have been seen under this sandstone, and at 7 miles east from Antiquity a thin bed is reported at 40 feet above it. Six miles below Antiquity this sandstone is 250 feet above the Pittsburg and no trace of coal appears in the interval. At Pomeroy the Pittsburg coal is above water and shows:

	Feet	Inches
Coal	1	0
Clay	0	2
Coal	4	0
Coaly shale	1	2

There, as throughout Meigs county, a great sandstone comes down upon the Pittsburg or is separated from it at most by 15 feet of shale; it is from 60 to 70 feet thick.

The higher coal beds are to all intents wanting, as in southern Washington county. The Pittsburg reappears at perhaps 16 miles below Parkersburg, where it has been found in an oil boring; thence it increases and becomes of importance at Antiquity, whence it is a workable bed into Gallia county.

The great sandstone shown at Antiquity is readily traceable along the Ohio from its first appearance at the southern edge of Washington county. As described by Doctor White, it is coarse and massive, with pebbly streaks containing quartz pebbles at times an inch in diameter. No reference is made to it by Professor Andrews in his report on Athens county and none of his sections reaches to it, the longest being only

to 187 feet above the Pittsburg coal bed; but Professor Lovejoy gives in his generalized section for Meigs county a sandstone, 30 to 50 feet thick, at about 270 feet above the Pittsburg. In Athens county, very near the Meigs border, Professor Andrews has this sandstone at about 40 feet above that resting on the Uniontown coal bed, and Professor Lovejoy seems to have followed it around. It seems, therefore, altogether probable that the lower sandstone, that overlying the Uniontown coal bed, has disappeared as a great sandstone throughout Meigs, as it did on the Ohio river in Washington county, and that here in this higher sandstone we have the equivalent of the Waynesburg sandstone belonging to the Dunkard formation; but the Waynesburg coal bed seems to be represented only by a mere blossom, as is also the Upper Sewickley in Meigs county, while no trace of the Uniontown remains.

Professor Andrews's sections show a bed of red shale 12 to 18 feet thick at 164 feet above the Pittsburg in two localities; one of 14 feet at 140; one of 18 feet at from 117 to 120, and one of 6 feet at 100 feet above the Pittsburg, while at times the upper part of the Pittsburg sandstone is replaced by red shale.*

Gallia county is south from Meigs, along the Ohio river. The Pittsburg coal bed is present in the northern part of the county, near the Meigs border, but only in isolated patches, and the coal has little cover. It is 4 feet 6 inches near the Meigs line, but, decreasing, is only 1 foot 6 inches at a few miles south. It is overlain by sandstone, which at one locality near Gallipolis is broken by red shale, 10 feet, at 17 feet above the coal.

An insignificant area remains on Greasy ridge, in Lawrence county, 8 to 10 miles west from the Ohio river. There Mr McMillin measured a thickness of 4 to 5 feet. This is the last fragment in Ohio, and the Monongahela is not reached by the Kentucky section.†

WEST VIRGINIA

Returning now to the east and entering West Virginia from Pennsylvania, one finds an insignificant patch of Monongahela remaining in the Blairsville-Connellsville basin, where the Pittsburg coal bed underlies a thick coarse sandstone and the Redstone coal bed, with its limestone, is absent. Two miles westward, beyond the Monongahela river, this sandstone has disappeared, and one finds a section very similar to

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* E. B. Andrews: Vol. i, pp. 253, 256 to 278.
E. M. Lovejoy: Vol. vi, pp. 627, 628, 629.
I. C. White: Op. cit., pp. 83, 84, 85, 86.

† E. B. Andrews: Vol. i, pp. 235, 236, 239, 240, 243.
Emerson McMillin in personal communication.

that of Greene county of Pennsylvania. The formation soon passes below the surface, and thence across the state it can be followed by means of oil-well records.

In Monongalia county, at a few miles south from the Pennsylvania line, one has the carefully measured section by Doctor White:

	Feet	Inches
1. Waynesburg coal bed	10	10
2. Black shale	1	0
3. Sandy shale	25	0
4. Waynesburg limestone	8	0
5. Sandy shales, layers of limestone	30	0
6. Massive sandstone	20	0
7. Limestone and shale	15	0
8. Black shale, Uniontown horizon	2	0
9. Limestone and thin shales	105	0
10. Sewickley sandstone	40	0
11. [Lower] Sewickley coal bed	5	0
12. Shale and sandstone	15	0
13. Limestone [Fishpot]	15	0
14. Shales and concealed [Fishpot]	23	0
15. Limestone [Fishpot]	7	0
16. Concealed	15	0
17. Redstone coal bed	4	0
18. Redstone limestone	18	0
19. Shale and slate	10	0
20. Pittsburg coal bed	13	10

The multiple Waynesburg bed has this structure:

Coal, 2 feet; shale, 1 foot; coal, 1 foot 4 inches; shale, 1 foot 6 inches; coal, 5 feet;

and the Pittsburg is:

Roof, coal, and slate, 3 feet 3 inches; clay, 1 foot; Main coal, 9 feet 7 inches.

The total thickness of the formation is 372 feet 8 inches. The interval from Waynesburg to Uniontown is 99 feet and that to the Lower Sewickley is 246 feet. At Fairmont, 20 miles south, in Marion county, the intervals are almost the same, the Redstone coal bed is absent, and the Waynesburg, with 4 feet 6 inches of coal, is barely 6 feet thick. The Waynesburg, Uniontown, Benwood, Fishpot, and Redstone limestones are all present and distinct, but no trace of the Little Waynesburg coal bed appears in any of the sections.

The measurements of two cores from diamond drill are available a few miles west—one in Monongalia county measured by Mr J. E. Barnes,

the other near Farmington, in Marion county, measured by Doctor White,

	Feet	Inches	Feet	Inches
Waynesburg coal bed........	7	7	6	0
Interval	225	0	299	9
Lower Sewickley	6	8	6	4
Interval	77	4	107	2
Pittsburg coal bed...........	9	1	9	1
Totals	325	8	428	4

showing a remarkable increase in intervals southward; so that at the latter locality, 8 miles west from Fairmont, one has the greatest recorded certain thickness for the Monongahela. At the northern locality the Uniontown limestone, as near Morgantown, in Doctor White's section, is almost continuous with the Benwood, but at the southern it is distinctly separate. The Uniontown coal bed, wanting in the Monongahela core, is present in that from Farmington, where, however, the Redstone is not present. The sandstones are very pronounced in the Farmington section, and that just below the Waynesburg coal bed is so massive that it is named by Doctor White the Gilboy sandstone. Red shale, absent in the northern core, is present at Farmington, 5 feet thick at 47 feet below the Uniontown coal bed.

In Monongalia county the formation thickens westwardly. Some wells about 10 miles west from the river record 330 to 340 feet between the Waynesburg and Pittsburg and one at 20 miles gives the interval as 363 feet, with total thickness of 377. The Lower Sewickley coal bed is present in all the records giving any details. In Marion, along a line passing southwest about 12 miles northwest from Fairmont, the interval from Waynesburg to Pittsburg is 325 near the Monongalia line, but at Mannington, 2 or 3 miles west from Farmington, it is 390 feet. The Lower Sewickley is present in all of the records at 225 to almost 290 feet below the Waynesburg, but the Redstone seldom appears. The Sewickley sandstone is well marked except near Mannington. As the records are of the ordinary type, they afford no information respecting the limestones. The Waynesburg, Lower Sewickley, and the Pittsburg coals persist to the western border of the county, but records on that side give no information respecting the intervening rocks.*

Wetzel county, west from Monongalia and Marion and south from Marshall, extends to the Ohio river, where it adjoins southern Monroe

* I. C. White: Geology of West Virginia. Vol. i, pp. 232, 234, 236, 238, 239, 241, 246, 247, 248; vol. ia, pp. 163, 164, 165; vol. ii, 127, 128, 129. Bulletin U. S. Geol. Survey, no. 65, p. 48.

J. E. Barnes: Cited in vol. ii, p. 127.

of Ohio. In the eastern part of the county the Waynesburg is 237 to 244 feet above the Lower Sewickley and 330 to 350 feet above the Pittsburg. A core obtained at Pine Grove, midway in the county, and measured by Doctor White, shows the Pittsburg, Redstone, Lower Sewickley, Uniontown, and probably the Waynesburg coal beds, all of them very thin, none exceeding 2 feet 2 inches. The Waynesburg and Uniontown limestones are wanting, but the Benwood, Fishpot, and Redstone are still present. The intervals shown by this core are:

	Feet	Inches
Waynesburg coal bed	0	6
Interval	96	0
Uniontown coal bed	1	6
Interval	143	11
Sewickley coal bed [Upper (?)]	2	2
Interval	79	6
Redstone coal bed	1	7
Interval	24	9
Pittsburg coal bed	2	2

In the northeast corner of the county, adjoining Monongalia, the Waynesburg is 340 feet above the Pittsburg and in the southeast corner the interval is 350 feet, with the Washington at 165 feet above the Waynesburg. Midway along this line the Uniontown is recorded at 277 feet above the Pittsburg and 230 feet below the Washington, the intervals being greater than at Pine Grove. There the Washington is but 484 feet above the Pittsburg, and at a little way northeast the interval is 475. Very possibly the little coal at Pine Grove correlated with the Waynesburg may be a local streak or one whose thinness has prevented recognition at surface exposures. The interval to the Pittsburg, 359 feet, is too great, in view of decrease in other intervals. The Waynesburg and Uniontown coal beds are so thin that they have been overlooked by the drillers at most places, but on the northern border of the county, at 10 miles east from the Ohio river, the interval from the Washington has decreased to 446 feet, and there is another bed at 356 feet. One mile farther north, in Marshall county, cores obtained by Mr. Barnes show the Waynesburg at 306 feet and the Uniontown at 233 feet above the Pittsburg. The first coal bed above the Waynesburg would be about 120 feet above the Uniontown. Where the formation comes to the surface, 10 or 12 miles farther northwest, the Waynesburg, 55 feet above the Uniontown, is but 238 feet above the Pittsburg and 110 to 115 below the Washington. There are no well records near the Ohio river, but a section at that river in the extreme northwest corner of the county shows the Uniontown, said to be 3 feet thick, at 75 feet above the river and, as

at Proctor, 10 miles east, 120 to 125 feet below the Waynesburg A coal bed. The Waynesburg seems to be wanting, but a sandstone answering to the Gilboy horizon and extending upward to beyond the place of the Waynesburg is present.

The Pittsburg coal bed is persistent in eastern and northern Wetzel, though evidently varying much in thickness, but in western Wetzel it is extremely irregular, often represented only by black shale. There is much sandstone above the Uniontown coal at Pine Grove as well as along the Ohio river, but in the eastern part of the county the interval to the place of the Waynesburg seems to carry mostly shale. Red shales are wanting at Pine Grove, but a detailed record at a few miles east shows 5 feet resting on the Pittsburg and 35 feet at 238 feet higher, underlying the place of the Uniontown coal bed. The Pine Grove boring shows 88 feet of limestone in the Benwood interval, the Fishpot is represented by 11 feet of limestone and 14 feet of calcareous shale, while limestone fills half the interval from the Redstone to the Pittsburg. The other records give no trustworthy information respecting the limestones.*

Returning now to the east, one finds the outcrop in the western third of Taylor and Barbour counties and in eastern Harrison, where the lower part of the formation is above drainage. The only available section in the former counties shows no Waynesburg, Uniontown, or Sewickley, as their places are concealed, but a coal bed, probably the Redstone, is at 32 feet above the Pittsburg, 5 feet thick and accompanied by its limestone, 11 feet. A white limestone 5 feet thick and 175 feet above the Pittsburg is thought by Doctor White to be the only representative of the Benwood. A succession of sandstones beginning at 125 feet above the Redstone coal bed culminates in a massive rock, very pebbly at 458 feet above the Pittsburg, whose place is very uncertain. A section by Mr J. L. Johnson at Clarksburg in Harrison county is:

	Feet	Inches
1. Massive sandstone	Not measured	
2. Concealed and yellow shale	65	9
3. Sandstone	25	0
4. Concealed some limestone	80	0
5. Sandstone and sandy shale	46	0
6. Sewickley sandstone	40	0
7. Shale	10	0
8. Sewickley coal bed [Lower]	1	0
9. Limestone [Fishpot]	9	0
10. Concealed, shale, sandstone	31	0
11. Redstone coal bed, slaty	3	0

* I. C. White: Vol. i, 339, 340; vol. ia, pp. 177, 178, 187, 192, 196, 202; vol. ii, pp. 136, 139. Catalogue of West Virginia University, 1883-1884, p. 66.
J. E. Barnes: Cited in vol. ii, p. 131, 132.

	Feet	Inches
12. Shale	5	0
13. Redstone limestone	6	0
14. Shale	13	0
15. Pittsburg coal bed	8	6

The sandstone at the top of the section is 320 feet above the Pittsburg coal bed. Stevenson's sections along the railroad beyond Clarksburg show the Redstone and Sewickley at 20 and 41 feet above the Pittsburg, with the Sewickley sandstone, 40 feet thick, at 6 feet above the coal bed. On top of the sandstone is black shale, 6 feet, containing 2 inches of coal and marking the place of the Upper Sewickley. The Benwood limestone is represented by only 7 feet of limestone and calcareous shale, at about 8 feet above the Upper Sewickley. Stevenson reports a coal bed at Clarksburg, 160 feet by barometer, above the Lower Sewickley; but this interval cannot be depended on, as all of the intervals by barometer given in the paper here quoted are too small. This bed may be at the Uniontown horizon. It is identified with a bed seen at 9 miles west from Clarksburg, 4 feet thick, divided by one foot of clay.

At Brown's mills, 10 miles northwest from Clarksburg, a record kept with unusual care shows:

	Feet
1. Waynesburg sandstone	25
2. Waynesburg coal bed	3
3. Slate	15
4. Gilboy sandstone	35
5. Shale	80
6. Uniontown coal bed	5
7. Shale and "limestone"	265
8. Pittsburg coal bed	10

Doctor White has recognized the Waynesburg, Waynesburg A, and Washington coal beds in surface croppings near this boring, so that there remains no room for doubt respecting the correlation. The Gilboy sandstone, whose top is 385 feet above the Pittsburg, is no doubt included in the great sandstone at Clarksburg, whose bottom is 320 feet above that coal bed, for, as will be seen, the bed varies greatly in thickness. A detail record 3 miles eastwardly from Browns shows no coal at the place of the Waynesburg, the sandstone is wanting, and the Washington coal bed is 538 feet above the Pittsburg, 23 feet more than in southeast Wetzel, 10 miles northwest. Near Cherry Camp, on the Baltimore and Ohio railroad, 10 miles west of south from Browns and a similar distance west from Clarksburg, a detailed record shows the Washington at 568, the Waynesburg A at 481, and the Uniontown, 2 feet thick, at 287 feet above the Pittsburg. The intervals are all larger than at Browns. The

Gilboy sandstone is 25 feet thick and 94 feet above the Uniontown, the same as at Browns, making allowance for thinning of the rock. At Salem, west from Cherry Camp, the Washington is 546 feet above the Pittsburg; no Waynesburg is here, but a 35-foot sandstone is at 405 feet, as at Browns. Farther south, in western Harrison, a Sewickley coal bed is at 80 and the Uniontown coal bed at 280 feet above the Pittsburg.

The Pittsburg coal bed attains great thickness in Harrison, Barbour, and Lewis counties. The roof division, so well marked in most of Pennsylvania and Ohio, is seen rarely, but very often a black slate rests on the "over-clay." The thickness from Clarksburg eastward is not far from 8 feet and one opening shows almost 9. There is a tender middle bench, the "bands," answering to the "bearing-in-bench" of Pennsylvania and Ohio, separating the "breast" from the "bottom." The "breast" usually contains a good deal of hard coal, often much semi-cannel, but the "bottom" is a softer coal, lower in ash, and all very good except a few inches on the floor. The whole bed gives marketable coal. The thickness decreases west from Clarksburg and at times falls to 5 feet.

The only red shale recorded in the Clarksburg region is a thin bed, sometimes replacing the upper part of the Sewickley sandstone. There is none in the Brown record; but records farther south, on the west side of the county, show 10 and 30 feet at 250 and 349 feet above the Pittsburg, the former belonging to the deposit below the Uniontown and the latter underlying the Gilboy sandstone, which in turn underlies almost immediately the place of the Waynesburg coal bed.*

Doddridge county, west from Harrison, is south from Wetzel and Tyler. At Sedalia, on the eastern border, 7 or 8 miles south of west from Browns and 6 or 7 miles northwest from Cherry Camp, is the measurement of a core obtained by Mr Barnes, thus:

	Feet	Inches
1. Mostly shale	61	0
2. Black and gray shale	2	0
3. Blue shale	4	0
4. Sandy shale	12	0
5. Sandstone	83	0
6. Blue shale	17	8
7. Coal bed [Uniontown]	3	2
8. Shales and limy shales	184	2
9. Coal bed	0	6
10. Shales and sandstones	83	0
11. Pittsburg coal bed	6	10

* I. C. White: Bulletin no. 65, pp. 49. Geology of West Virginia, vol. i, pp. 248, 250; vol. ia, pp. 316, 317, 319, 320; vol. ii, pp. 139, 140, 141.
J. J. Stevenson: Proc. Am. Phil. Soc., vol. xiv (1875), pp. 377, 378, 381.

Here one is 18 miles southeast from Pine grove, in Wetzel county. The Uniontown coal bed is almost 268 feet above the Pittsburg. At Browns the interval is 265, and at Cherry Camp 287 feet. The top of the Gilboy sandstone at Browns is 385, at Cherry Camp about 400, and at Sedalia 371 feet above the Pittsburg. At Sedalia there is a little black shale at 388, and at Browns the Waynesburg coal bed is at 400, underlying a sandstone which at Salem is 405 feet above the Pittsburg. The elements of the section are the same throughout and the varying intervals are but sums of variations in the subordinate intervals. The great sandstone at Sedalia is the Gilboy of earlier records, increased downward so as to embrace most of the underlying shale at Browns. The interval decreases westwardly, and at 10 miles from Sedalia the Uniontown is 250 feet above the Pittsburg, with no coal in 168 feet above to the top of the well. The Waynesburg is evidently gone, as no trace of it appears in intervening records. Here one is on the border of Tyler county and about 11 miles southwest from Smithfield, in Wetzel, where the Waynesburg is present, and 350 feet above the Pittsburg.

Long run, on the Baltimore and Ohio railroad, is 7 miles west from Cherry Camp. A well record gives the Pittsburg as 3 feet thick, but no clear record is given above that coal bed. Along the railroad from Long run westward to West Union, midway in the county, one often sees a coal bed underlying a massive pebbly sandstone. The structure of the bed is remarkably like that of the Waynesburg farther north, and for that reason Stevenson correlated it with that bed, regarding the overlying plant shales as equivalent to those now known as the Cassville. The section at Smithton is:

	Feet	Inches
1. Shale, with impressions of plants	4	0
2. Coal	2	2
3. Clay	0	3
4. Coal	0	2
5. Cannel	0	3
6. Shale	8	6
7. Coal	1	6

The material here available may not suffice to justify positive correlation of this bed, but it can hardly be the Waynesburg, for that bed seems not to extend so far south, while the conditions at Long run and in counties beyond seem to justify the assertion that it must be very near the place of the Uniontown, as Doctor White has suggested. Its resemblance in structure to the Uniontown of Monroe county, Ohio, is very remarkable. Detailed records are too few in Doddridge county to

enable one to speak finally about distribution of the red shales. The bed belonging under the Uniontown coal bed is 15 feet thick on the Tyler border, but along the eastern side the beds are thin and unimportant.*

Tyler county, southwest from Wetzel along the Ohio river, is northwest from Doddridge and adjoins northern part of Washington county of Ohio. The number of oil wells in this county is very great, but for the most part the records are merely skeletons in much of the county, comparatively few making any note above the Pittsburg horizon. That coal bed is recorded in many wells along the Doddridge border, but is absent from many others, while in by far the greater part of the county it is represented by a mere trace or is wholly wanting; but the horizon can be carried without difficulty along the strike lines by means of the Logan (Big Injun) sandstone.

A record just over the line in Doddridge county notes the Uniontown coal bed at 250 feet above the Pittsburg. In southeast Tyler, near Wick, a detailed section shows the Uniontown, very thin, at 253 feet above the Pittsburg and 36 feet above a 15-foot bed of red rock, which is very near the place of a bed in a Doddridge well 10 miles northeast. At Wick this coal bed underlies 30 feet of coarse sandstone, as it does near Smithton, 5 or 6 miles southeast on the railroad, and it is 191 feet below the Washington, a very notable decrease from Harrison county, where the interval is 273 feet within the Sardis district. The Washington is 538 feet above the Pittsburg in Sardis, but only 444 feet in southeast Tyler. The interval, Uniontown to Washington, is almost 30 feet less than at Pine Grove, in Wetzel, 20 miles north-northeast.

More information is available along a line 7 to 8 miles northwest from this Pine Grove-Wick line. The Uniontown coal bed is noted in most of the records giving any information above the Pittsburg horizon. On the Wetzel border, 6 miles east of south from New Martinsville and at the same distance southeast from Sardis, in Monroe of Ohio, the interval from Uniontown to Pittsburg is 240 feet; farther southwest to the Ritchie-Pleasants line the Uniontown is almost constantly present at 1,460 to 1,470 feet above the Logan sandstone and 220 to 230 feet above the Pittsburg, where that bed is present. The interval to the Pittsburg decreases still more toward the west, becoming 210, and then 200, while at 8 miles from Middlebourne, on the Pleasant border, a record shows what seems to be this bed at 177 feet. The changes in relation to the Washington are quite as interesting as those in relation to the

* I. C. White: Vol. i, pp. 325, 328, 330, 331, 332; vol. ia, p. 283; vol. ii, p. 138.
J. E. Barnes: Cited in vol. ii, p. 138.
J. J. Stevenson: Proc. Am. Phil. Soc., vol. xiv, pp. 376, 377.

Pittsburg. The latter interval has decreased gradually from 288 feet in Harrison to certainly 200 and possibly 177 in western Tyler; that from the Washington has decreased from somewhat more than 270 in Harrison to 180 at the last record in western Tyler, the decrease in this case being as gradual as in that of the other interval. The Waynesburg coal bed is not noted anywhere in Tyler. No coal or trace of coal appears in record between the Uniontown and the Pittsburg. Only two detailed records are available for this county. That in the southeast corner shows red beds at 203 and 283 feet above the Pittsburg, and one in the southwest shows a bed 75 thick at 79 feet below the Uniontown horizon, that coal bed being absent, having been cut out by downward extension of the overlying sandstone.*

Pleasants county, west from Tyler along the Ohio river, adjoins Washington county of Ohio. A coal bed is reported in a well near the northeast corner of the county at 1,227 feet above the "Keener" sandstone. Near Middlebourne, in Tyler, the Pittsburg is 1,229 feet above the "Keener," and in another well near the Pleasants border it is 1,252 feet above the bottom of that sandstone. The bed in northeast Pleasants is very near the place of the Pittsburg, but its occurrence is of merely geological interest, as the bed is insignificant, the driller reporting only 3 feet in all. At Saint Marys, on the Ohio river, the Uniontown coal bed is 2 to 3 feet thick and underlies a massive sandstone which is traceable up the river almost to the Tyler line. There the interval to the Washington has decreased to 160 feet, 20 feet less than at the last measurement in Tyler county. No record is here to determine the distance to the Pittsburg, but at a few miles west, in Washington county of Ohio, the Uniontown is 186 feet above the Pittsburg. Borings along the Ohio river find no trace of the Pittsburg coal bed, which is very thin in the adjacent part of Ohio.†

Ritchie county, west from Doddridge, is south from Tyler and Pleasants. The Monongahela is deeply buried except near the western border, where the Cowrun anticline brings up still lower rocks. The Pittsburg coal bed is of extremely uncertain occurrence and the detrital beds vary abruptly, as appears in numerous detailed records. In the northeast corner the Uniontown, very thin, is 237 feet above the Pittsburg, 16 feet less than at Wick, 3 or 4 miles northeast; 2 miles farther south 25 feet of hard sandstone appear at 230 feet above the Pittsburg, evidently that belonging over the Uniontown coal bed on the railroad in Doddridge county. Farther south along this eastern side, for 9 or 10 miles the Pittsburg coal

* I. C. White: Vol. i, 332; vol. ia, pp. 240, 248, 249, 250, 251, 252, 255, 256, 258, 266, 268.

† I. C. White: Vol. i, p. 354; vol. ia, 269, 273.

bed is rarely absent from the records and varies from 2 to 6 feet, shale included, but all the records are skeleton and give no information above that bed. Westward the Pittsburg soon disappears, but its place in relation to the Logan sandstone is clear, so that the horizon is followed for the most part without difficulty. At 8 miles west from the Doddridge line the Uniontown, 2 feet thick, is about 235 feet above the Pittsburg, while midway in the county it is 3 feet thick, with a streak of coal at the Waynesburg horizon, 51 feet higher. North from the railroad and 12 miles from the Doddridge line a coal bed is at 215 feet below the Washington; 9 or 10 miles southwest, near Harrisville, this bed is at 223 feet below the Washington, but at Harrisville no trace of coal is recorded, though the bed is present 3 miles south from that village. This seems to be the Uniontown, though it is about 260 feet above the calculated place of the Pittsburg. All coals are wanting in the western part of the county, there being no trace in any record of any below the Washington.

Limestone appears to be wholly wanting, as the drillers rarely make mention of even "limy shale;" but the red beds appear throughout the section. Tabulating the records, one finds that red shale occurs in some well or other at every foot in 300 feet above the place of the Pittsburg coal bed. Such shale is found in widely separated wells, filling part to all of the first 40 feet; thicknesses of 50, 45, 29, 35, 26 are recorded between 28 and 100 feet; between 100 and 165 feet are 60, 50, and 7 feet in different wells; in two wells, beds of 60 and 31 begin at 165 feet; in three wells one finds beds 85, 110, and 25 feet, beginning at about 180. The interval 180 to 290 feet is marked by thick red beds, sometimes a continuous mass; at others divided into two or more; in one case divided by the Uniontown coal bed. The highest which can possibly be in the Monongahela is at 308 feet, 10 feet below a sandstone which may be the Waynesburg. Two great beds are on the west side of the county, 75 and 100 feet thick, but it seems hardly possible to determine their relations.*

Wirt county is southwest from Ritchie. Very little information is available for this county. The Pittsburg is brought to the surface in the Cowrun anticline, or "Oil-break," and a section by the late Mr Minshall obtained near Burning Springs shows:

	Feet	Inches
1. Waynesburg [Uniontown] coal bed........	1	8
2. Concealed and shales....................	207	0
3. Pittsburg sandstone	30	0
4. Shale	10	
5. Pittsburg coal bed......................	1	8

* I. C. White: Vol. i, pp. 302, 303, 304, 305, 311, 313, 317; vol. ia, pp. 410, 426, 435, 439.

giving a total of 250 feet. It is evident that the Waynesburg coal bed of the section is that which has been followed across the region as the Uniontown. A record on the east side of the county reports 5 feet, and one on the west side 3 feet of coal at the Pittsburg horizon; but Doctor White states that the coal is frequently absent.*

Wood county, west from Pleasants, Ritchie, and Wirt, adjoins Washington and Meigs of Ohio. In this county there is little to correlate; the coal beds have disappeared, even the Washington, the persistent bed of the Dunkard, becomes indefinite; the varying thickness of the Lower Carboniferous limestone makes it impossible to use either the Logan sandstone or the Berea grit as a datum except within the narrowest areas. At Parkersburg, on the Ohio, the presence of the Brookville coal bed enables one to fix approximately the place of the Pittsburg; it is at the top of a mass of red and blue shale, not far below a sandstone 31 feet thick, above which red shale seems to predominate. The most notable feature of the well records in various parts of the county is the great quantity of red shale, beginning often in the Conemaugh and continuing many feet up into the Monongahela. The conditions change abruptly in short distances, thick reds in one well being absent in another and sometimes replaced by sandstones.†

Returning to the east, we find that the Pittsburg coal bed has been mined in Upshur county near Buckhannon, where it is 4 to 5 feet thick, and an opening near the line of Barbour county shows it 5 feet 6 inches, with a very thin parting almost midway. The coal in the upper bench is hard, contains much semi-cannel, and leaves a bulky red ash; that in the lower bench is tender, with thick layers of brilliant, structureless coal, showing no lamination and with conchoidal fracture. These layers are 2 to 4 inches thick and the coal from the whole lower portion leaves a white ash. The roof division of the bed seems to be wanting there. In Lewis county, the Pittsburg is from 4 to 8 feet thick, the variation being mostly in the upper bench. The same distinction in character of the coal is shown here, and so marked is it that where no parting exists the limits of the benches are well marked. Another coal bed is at a little distance above the Pittsburg, and in Lewis county the Uniontown is 275 feet above the Pittsburg and very thin.

The Pittsburg is present in Braxton county south from Lewis, but in economic quantity only on the western or Gilmer side, where it is from 5 to 6 feet thick, the variation being in the upper bench. It becomes thin toward the southeast and disappears before the outcrop has

* I. C. White: Vol. ia, pp. 467, 468.

† I. C. White: Vol. i, pp. 285, 286, 292, 293, 294, 295.

been reached. The bed persists toward the southwest to the boundary line, though sometimes only 3 feet thick. In the extreme southwest it is 175 feet below a massive sandstone. The coal is present in separated patches across northwestern Clay and southern Roane county, varying from 2 to 4 feet. It underlies a sandstone which persists southeastwardly and is present at Clay courthouse, though the coal has disappeared. No higher coal bed is reported anywhere within Braxton, Clay, Roane, and the immediately adjacent part of Kanawha county, and at the border of the last county the Pittsburg has only a few inches of very impure coal. Thence it is wholly wanting for about 10 miles, but reappears suddenly, about 4 feet thick, at the head of Two-mile creek, where it shows:

	Feet	Inches
Roof coal	0	6
Clay	1	0
Bony coal	0	6
Coal	3	0
Bony coal	0	1
Coal	3	6

But its occurrence is very uncertain. It is mined within some small areas near Raymond City and Winfield, in Putnam county, where at times it becomes thick and has a structure like that observed in typical localities at the north; but for the most part in this Kanawha region it is wanting and coal rarely appears above it; so that one recognizes the force of Mr M. R. Campbell's statement, that no line can be drawn between Allegheny and Dunkard for the Kanawha area. He groups the upper Conemaugh, Monongahela, and Dunkard together into one, which he terms the Braxton formation—a succession of greenish and reddish shales and sandstones. Doctor White's sections show an abundance of red shale in 200 feet above the Pittsburg horizon. The Pittsburg coal bed appears to be practically wanting in Cabell county west from Putnam, but is caught near Central City and Huntingdon, where it is more than 4 feet thick. A petty area remains in Wayne county 8 miles south from Central City, where the bed is 3 feet thick. No place is known in Kentucky where the section is high enough to reach this coal.*

In Gilmer county, west from Lewis, a massive pebbly sandstone very like the Waynesburg overlies the Uniontown coal bed and is apparently the same with that in the Sedalia boring and along the Baltimore and Ohio railroad in Doddridge county. The Uniontown coal bed is shown

* I. C. White: Vol. ii, pp. 144, 149, 162, 163, 181, 185, 186, 188, 190, 191.
M. R. Campbell: U. S. Geol. Survey folios, Huntingdon.
J. J. Stevenson: Proc. Am. Phil. Soc., vol. xiv, pp. 377, 378.

under it quite frequently in Gilmer county, where, as in Lewis, it is known as the Chestnut Oak coal. Doctor White found impure limestones, 2 and 3 feet, at 135 and 22 feet above the Pittsburg, the higher bed only 10 feet below the great sandstone. Other massive, more or less pebbly sandstones, each 40 feet thick, are at 55 and 147 feet above the Pittsburg coal bed. That bed varies greatly in Gilmer county, sometimes double and 7 feet thick; at others with only the lower bench, while in a large part of the county it is wanting. Red shale is reported from a few places in Gilmer; there is much of it at the southeast, near the Braxton border, and a well at the northeast near the Lewis line reports 76 feet at 175 feet above the Pittsburg—a deposit widespread in other counties—while on the western border 88 feet thickness overlies the calculated place of the Pittsburg coal.*

Calhoun county, southwest from Gilmer and southeast from Wirt, is east from Roane. The conditions are very obscure in Calhoun and Roane and one may draw only tentative conclusions from the records, which prove little more than that the series is unbroken by any physical boundary from the Conemaugh to the Dunkard. One Calhoun record shows a thin coal bed, not far from the place of the Pittsburg, underlying 125 feet of red shale, on which rests a sandstone 50 feet, but another gives only 60 feet of red shale in two beds within the same interval. A record in northern Roane shows apparently the same sandstone resting on 15 feet of red, but there is no more red in 250 feet below. The red shales are less important in northern Roane than in Ritchie and Wood, the greatest thickness being 84 feet in four beds within 225 feet above the presumed Pittsburg horizon.†

Jackson county, west from Roane and Wirt, is south from Wood, along the Ohio river. In the southern part, near Kenna, 10 miles from Sisson, north from Sissonville, in the Kanawha area of Pittsburg coal, a detailed record shows no coal at that horizon; but it may be that the horizon is represented by 24 feet of carbonaceous shale underlying 22 feet of sandstone. Above the sandstone for 316 feet are only shales holding two red beds, 92 and 58 feet, at 84 and 240 feet above the black shale. Twenty-two miles northwest is a record at Ravenswood, on the Ohio, starting near the place of the Washington coal bed. The Pittsburg coal bed is here, reported 5 feet thick, and underlying a sandstone of 53 feet. Red shales 12, 8, and 10 feet are at 73, 151, and 186 feet above the coal, and above the highest bed there is evidently a sandstone, though it is not

* I. C. White: Vol. i, p. 257; vol. ia, p. 386; vol. ii, pp. 142, 182, 186.

† I. C. White: Vol. i, p. 264; vol. ia, pp. 395, 396; vol. ii, pp. 398, 399.

differentiated. At Ravenswood this sandstone, coarse and pebbly, is in the river bed, and at Murraysville, 10 miles farther up the river, it has a thin coal bed under it. This sandstone, which passes under the Ohio at Blennerhassett island, 4 miles below Parkersburg, is apparently the same with a sandstone, 15 feet, in the Parkersburg well, 28 miles from Ravenswood, and it apparently becomes unimportant farther north, as there seems to be no trace of it at Marietta, Ohio.*

In Mason county, west from Jackson, there is no information available except along the Ohio and Great Kanawha rivers. At Letart falls, 12 miles west from Ravenswood, the sandstone is 273 feet above the Pittsburg, which is worthless, its carbonaceous matter, as at Kenna, being distributed through a great thickness of black slate. It underlies 8 feet of sandstone on which rests a red bed 115 feet thick. Other red beds succeed, but they are not differentiated in the record, until at 213 is another, 60 feet thick and extending to the sandstone. At Antiquity, 6 miles below Letart falls, the sandstone is 241 feet above the Pittsburg, with the interval mostly concealed; but at 11 miles another section shows the interval 250 feet, with several beds of red shale. A massive, somewhat pebbly sandstone, 70 feet thick, is separated from the Pittsburg coal bed by 15 feet of plant-bearing shale. Limestone seems to be wholly wanting, aside from some nodules at 193 feet.

The Pittsburg coal bed, as in Ohio, very soon becomes unimportant below Pomeroy, and at Point Pleasant, near the mouth of the Great Kanawha river, it is only 2 feet thick and impure. The decrease continues southeastwardly, for a boring at Arbuckle, 15 miles from the mouth of the river, shows only some coaly slate at its horizon. A coal bed, possibly at a Sewickley place, is 89 feet higher, and at 268 feet is a mass of coal and slate, 3 feet thick, underlying a massive sandstone, which may be the Waynesburg.†

The Dunkard Formation

CORRELATION

The Dunkard area is much smaller than that of the Monongahela, embracing little more than 7,000 square miles. It is confined to Washington and Greene counties of Pennsylvania, the western central counties of West Virginia and Belmont, Noble, Monroe, Washington, and Meigs of Ohio. Small outlying areas occur in other counties, but they are

* I. C. White: Vol. *ia*, p. 478. Catalogue of West Virginia University, 1883-1884, pp. 83, 84.

† I. C. White: Vol. i, p. 281; vol. ii, pp. 142, 143. Catalogue of West Virginia University, pp. 85, 86, 87. Bull. U. S. Geol. Survey, no. 65, p. 54.

insignificant. At one time the beds of this formation were continuous eastward to beyond the Alleghenies, as fragments remain in Maryland and west central Pennsylvania. The extreme thickness, as found in the southwest corner of Pennsylvania at the West Virginia line, and determined by oil-well records, is a little less than 1,200 feet. The thickness decreases greatly toward the north, the bottom 475 feet becoming about 165 feet at the most northerly exposure and the succeeding 240 feet is reduced to 150 feet at its northernmost exposure, nearly 30 miles south from that of the lower interval. There is a similar decrease in a northwestward direction, and toward the southwest one finds the bottom 700 feet of the thickest area reduced to barely 500 feet in Tyler of West Virginia, 35 miles away. Nothing can be determined respecting conditions toward the east, as erosion due to great anticlines prevents comparison with the fragments east from the Alleghenies in the deep basins of Broad Top and Maryland.

In the original description of this formation as it is in Pennsylvania, Stevenson divided it into the Washington County and the Greene County group, placing the plane on top of the Upper Washington limestone. Aside from the convenience of a division in a column of such length and complexity, one must recognize in the physical conditions good reasons for this separation. These, as will be seen, appear only in part along Dunkard creek, where Doctor White's studies led him afterwards to group the whole succession into one formation, the Dunkard. They are best shown farther north, in central Greene county, where they justify a return to the original grouping and to the recognition of the Washington and Greene formations as of equal rank with the Monongahela and others below.

As the Dunkard column is almost as long as the total of Allegheny, Conemaugh, and Monongahela in the northern part of the field, the characteristic deposits are numerous, most of them exhibiting peculiarities deserving of notice. In ascending order they are:

Washington formation:
- Cassville shale.
- Waynesburg sandstone.
- Waynesburg A coal bed.
- Colvin limestone.
- Waynesburg B coal bed.
- Little Washington coal bed.
- Washington sandstone.
- Washington coal bed.
- Lower Washington limestone.

Washington formation:
- Blacksville limestone.
- Washington A coal bed.
- Middle Washington limestone.
- Jollytown coal bed.
- Franklin limestone.
- Canton coal bed.
- Upper Washington coal bed.

Greene formation:
- Boyd coal bed.
- Ten-mile limestone.
- Pursley coal bed.
- Rogersville limestone.
- Jollytown limestone.
- Dunkard coal bed.
- Fish Creek sandstone.
- Hostetter coal bed.
- Nineveh limestone.
- Nineveh coal bed.
- Nineveh sandstone.
- Limestone XI.
- Limestone XII.
- Baresville coal bed.
- Jackson limestone.
- Gilmore sandstone.
- Windy Gap coal bed.
- Windy Gap limestone.*

The Cassville shale (I. C. White, 1891), 5 to 10 feet thick and resting directly on the Waynesburg coal bed, carries an important flora at many places. The type locality is in Monongalia county of West Virginia, where were obtained the plants described by Fontaine and White. This shale was removed from much of the area during deposit of the overlying Waynesburg sandstone. Limestone is persistent in it within western Washington county and thence across Ohio of West Virginia into Belmont of Ohio, but it is wanting in eastern Washington as well as in Greene and in the small areas of Fayette and Westmoreland.

The Waynesburg sandstone (J. J. Stevenson, 1872) is persistent around the borders of the area. In Maryland, Westmoreland, Fayette, eastern Washington, and Greene of Pennsylvania, as well as southward to Harrison county of West Virginia, it is a sandstone, usually massive

* While preparing this description the writer learned that not all of the original note books had been lost in the fire which destroyed the state capitol at Harrisburg. By request of Messrs A. S. McCreath and E. V. d'Invilliers, search was made and those covering Greene and Washington counties were discovered. By means of these it has been possible to remove some misconceptions due to incomplete publications of sections and to correct some errors of correlation due to rapid preparation of the report on that area.

and often to some extent conglomerate. In the interior of Washington county, as well as in Allegheny county, it is apt to be shaly, but in the western part of the former county it is usually massive. Oil-well records show it to be persistent as a massive sandstone in Greene county and the northern counties of West Virginia, often 70 feet thick and sometimes continuous downward to the Uniontown sandstone. Farther south the conditions are irregular; sandstone, often very thin, is generally present within the interval in Doddridge, Ritchie, and Wood counties. Farther south a sandstone is in Putnam county at about 240 feet above the Pittsburg. Though the tracing is not complete, enough is known to render most probable that this is the same with the sandstone of Jackson county and of Meigs in Ohio, which is the Waynesburg. Along this southern border the rock is massive, more or less conglomerate, with white quartz pebbles often an inch in diameter. In Meigs, Morgan, and Athens of Ohio it is the upper sandstone and conglomerate mentioned by Professor Andrews. Along the western outcrop it is insignificant in Muskingum, but farther north, in western Belmont, in Harrison, and southern Jefferson, it is a well marked sandstone. The sandstone of this interval is insignificant and at times replaced by sandy or even clayey shale within a large interior area embracing Ohio, western Marshall and Wetzel, Tyler, Pleasants, and Wood county of West Virginia as well as eastern Belmont, Monroe, and most of Washington county of Ohio.

The Waynesburg A coal bed...Maryland and Pennsylvania: Waynesburg A.
J. J. Stevenson, 1876. Ohio: XII, Washington. West Virginia: Waynesburg A, Washington.

This coal bed, just above the sandstone, is rarely more than 3 feet thick, usually much less and nowhere of even local importance. It is apparently absent from Allegheny county, but it was seen at almost every place in the four southwest counties of Pennsylvania, as well as in the northern counties of West Virginia. In Ohio it is distinct in Harrison, Jefferson, Belmont, and Monroe, where the observations are numerous, and it has been reported occasionally in Muskingum, Noble, and Washington, where recorded observations are very few. The geographical extent of this small bed is even more remarkable than that of the Uniontown, for the latter is of real value in a few areas, whereas this bed is always too thin to be of use. It differs from the Uniontown in that it is almost invariably coal, whereas the lower bed is often merely black shale for long distances.

The Waynesburg B coal bed (J. J. Stevenson, 1876) is equally insignificant in thickness and is found in only a limited area within south-

west Fayette, eastern Greene, and southern Washington of Pennsylvania. Even there it is irregular, being absent at many places where its horizon is fully exposed. The Little Washington coal bed (J. J. Stevenson, 1876) has much the same distribution as that of Waynesburg B, but the area is somewhat smaller.

A limestone, the Mount Morris (I. C. White, 1891), sometimes underlies the Waynesburg A coal bed, but it seems to be confined to small spaces. The typical locality is in southeastern Greene, but limestone is found occasionally at this level in West Virginia and eastern Ohio. The Colvin limestone (I. C. White, 1891), I*a* of the Pennsylvania volume K, is just above the coal bed and is present in Fayette and most of Washington county. It was seen at many places in eastern Greene, but is wanting in the western part of that county and is irregular in the southern part. It attains considerable thickness in Washington, but is usually thin in Greene. It barely enters West Virginia at the south. Another limestone, termed I*b* by Stevenson, is apparently confined to five townships in the west central part of Washington county, where it attains a maximum thickness of 10 feet. These limestones are all either nonfossiliferous or contain at most some indeterminate forms related to freshwater types. The rock is not magnesian in any case and sometimes the lime obtained from it is of excellent quality. The source of these calcareous muds is uncertain.

The Washington sandstone (J. J. Stevenson, 1876), underlying the Washington coal bed, is curiously persistent. Rarely more than 12 feet thick, it accompanies the Washington coal bed throughout Washington and Greene of Pennsylvania, Ohio and Monongalia of West Virginia, everywhere showing the same features. How much farther it extends is not known. It is thinly laminated, often crowded with fragments of carbonized vegetable matter, but seldom contains a leaflet in recognizable condition. Very often it is seamed vertically, and the slender seams are filled with lead-colored clay belonging to an underlying bed. These seams have no relation to jointing in the overlying and underlying coal.

The interval between the well marked Waynesburg and Washington coal beds shows the same kind of variation as that between the Waynesburg and Uniontown. At the extreme northern exposure of the Washington in Smith and Jefferson townships of Washington county, Pennsylvania, it is 50 feet above the Waynesburg. As one goes southwardly along the western side of the county he finds the interval 65, 83, 90, 95, 110, and 130 feet at the southern part of the county, beyond which in Greene the upper bed soon passes under. In a southeastward direction the interval becomes 65, 90, 110, 120, 125, and 142 and at the Greene

county line 160 feet; in this county it increases to 180. Westwardly, beginning in Donegal township of Washington, it is 90, near Wheeling, 96 to 100, at Bellair, 4 miles south, in Belmont, 117, while in western Belmont it is 100 feet, which seems to be maintained on most of the western outcrop. The Bellair interval seems to be approximately that for a considerable distance along the Ohio river, while in the northern counties of West Virginia the interval is from 160 to 170 feet. It is somewhat less by the time one reaches the central part of the state.

The Washington coal bed...... Maryland: Washington. Pennsylvania: J. J. Stevenson and I. C. White, 1876. Waynesburg, Washington. Ohio: XIII, Hobson, Washington. West Virginia: Washington.

This coal bed, 50 to 180 feet above the Waynesburg coal bed, has been found almost invariably wherever its horizon is reached in Maryland, Pennsylvania, Ohio, and West Virginia. It was termed Brownsville by Doctor White, but to avoid confusion with the Pittsburg, already known as the Brownsville in much of western Pennsylvania, the name was changed with his consent to Washington. In all probability it is the thick coal bed near the top of Round Knob in Broad Top and it is clearly recognized in the Maryland area. Its distribution in West Virginia toward the eastern border is a little uncertain, as there seems to be no doubt that it and the Uniontown have been mistaken each for the other in the earlier observations; but Doctor White has made clear that the bed is present at the southeast almost to the border of Clay county, while borings show it across the state to the Ohio, where from Wheeling to Pomeroy it is rarely missing; and in Ohio wherever the record is high enough to reach this bed it is shown in Belmont, Monroe, Muskingum, Morgan, Washington, and Meigs, all of the counties in which its horizon is reached.

The bed is multiple in by far the greater part of the area; even at the extreme east, in Maryland, it is triple, and of its 3 feet 6 inches 1 foot is in the clay partings. East from the Monongahela river, in Pennsylvania, it is rarely more than 4 or 5 feet, but one opening in Westmoreland county shows 9 feet 3 inches in five benches, of which the lowest is 4 feet 2 inches, while another, 3 or 4 miles away, has the bed in eight benches and 8 feet 10 inches thick. It is thin in Allegheny county and very irregular in northwestern Washington, where it is from 2 to 5 feet; but at less than 5 miles south it is a great bed, showing 5 feet of coal at one opening, on which rests a varying alternation of coal and clay 2 to 3 feet thick; still farther south one finds 1 foot 3 inches of coal under-

lying a great mass of black shale, while at a mile away the carbon is gathered into four benches and the bed is 6 feet 6 inches. The bed is usually thin in eastern Washington and Greene, but along the same area in Marion county of West Virginia it thickens and one section shows 10 feet 9 inches in 14 layers of coal and clay. Along the Baltimore and Ohio railway it is exposed frequently in Doddridge and Ritchie counties, showing the same complex structure observed at the northern exposures. Still farther south, in Calhoun and Roane counties, it is thin, rarely exceeding 2 feet 6 inches and containing, as so often at the north, the best coal at the bottom. Toward the west it becomes thin, being only 1 foot 3 inches in Ohio of West Virginia and reported in Ohio only as a blossom.

Almost without exception, coal from the Washington is inferior to that from the Waynesburg; yet it is mined for domestic fuel in a great area within the middle portion of the great trough, where the lower coals have disappeared. The coal-making conditions extended for the first time over practically the whole area, a notable change in geographical conditions.

The interval between the Washington coal bed and the Upper Washington limestone contains five important limestones and three coal horizons.

The Lower Washington limestone (J. J. Stevenson, 1876), 3 to 15 feet above the Washington coal bed, has been recognized in Maryland, and it is present at almost all places in Pennsylvania where its horizon is exposed. Doctor White has recognized it on the eastern side in West Virginia as far south as Tyler and northern Harrison, but toward the west it becomes insignificant, being very thin along the Ohio river and apparently wanting in most of Ohio. It is thin and often only calcareous shale in most of eastern Washington, but in the central part of the county it is from 15 to 33 feet thick, while on the west side it varies from 6 inches to 20 feet, these measurements being separated by only half a mile. In Greene county it rarely exceeds 3 feet. In Ohio county of West Virginia it is 20 feet thick at a few miles east from Wheeling, though thin at that city and apparently wanting 4 miles south at Bellair, Ohio. It usually underlies a black shale rich in carbon and often containing fish remains.

The Blackville limestone (I. C. White, 1891), III of volume K, at 25 to 70 feet above the Washington coal bed, is not reported from any locality east from the Monongahela river except in Redstone of Fayette county, Pennsylvania, but it is persistent in Allegheny, Washington, and Greene counties. It is not more than 3 or 4 feet thick at the most north-

erly exposure of its place in Allegheny county, but it quickly increases in northern Washington to 10 and to 30 feet. Unlike the Lower Washington, this deposit is insignificant in the central part of Washington county, where it is represented only by thin streaks; but it becomes better characterized in the southern part, where, as in Greene county, it is 3 to 4 feet thick. It disappears quickly west and south from the Pennsylvania line and it cannot be recognized certainly in any of the sections. It may be represented by one of the red beds. A black shale overlies this limestone at many places, and at times is rich in well preserved remains of fish. The Blacksville limestone was mistaken for the Middle Washington at several places in Allegheny and northern Westmoreland.

The Middle Washington limestone (J. J. Stevenson, 1876), numbered IV in volume K of the Pennsylvania reports, is not exposed in Pennsylvania east from the Monongahela river, where in all probability it is wanting. A limestone in Maryland has been correlated with this. The Middle Washington is present in most of Washington county, where its variations are very like those of the Blacksville, but its thickness is greater in a larger area; it practically disappears soon after passing into Greene county, and farther south it has been recognized only near the West Virginia border. There it is extremely sandy and weathers like sandstone; but it may be present in this condition elsewhere in the county. Unlike the Blacksville, this is always impure and often ferruginous.

The Franklin limestone (V of Stevenson, 1876) is exceedingly characteristic in Greene county, where it is coarsely brecciated and very hard, resisting the weather. It was mistaken by Stevenson for the Upper Washington in northwest part of the county where the higher limestone is very thin. This limestone, rarely more than 3 feet thick and often much less, is from 20 to 35 feet below the Upper Washington in Greene, where it is present at all localities exposing its place; it is present in the western townships of Washington at about 30 feet below the Upper Washington and its thickness exceeds 2 feet only twice. It was not seen in place in the central or eastern parts of the county, but its characteristic fragments were found in Franklin and Amwell townships very close to its proper position. It seems to be absent west from these Pennsylvania counties and Doctor White does not report it from West Virginia at the south.

The Upper Washington limestone (J. J. Stevenson, 1876), numbered VI, is the most persistent and in many respects the most striking member of this group. Its northernmost exposure is in northwest Washington

county, and thence southward it appears in every section, exposing its place in Pennsylvania until very near the West Virginia line. A limestone in Maryland has been correlated with this bed; the interval to the Washington coal bed, 192 feet, seems excessive, in view of changes in lower intervals in that direction, but no comparison can be made directly, as a gap of about 70 miles separates exposures. This limestone disappears southwardly very soon after entering West Virginia, and it cannot be recognized with any certainty in any of the long sections along the Ohio river south from Moundsville, West Virginia, where it is 244 feet above the Washington coal bed. In some of those sections, however, a red bed, with limestone nodules, is very near the place of this limestone.

The Upper Washington is flesh-colored, blue, and dark gray in its several portions, but all alike weather to an almost snowy white faintly tinged with blue; much of it is very pure and several of its layers waste very slowly on exposure. These features make the bed an unmistakable stratigraphical guide from its most northerly exposure to beyond central Greene county, as well as in the portions of Fayette county in which its place is reached. At the extreme north the bed is thin, but thickens southwardly to central Washington, where it is a mass of limestone and calcareous shale 20 to 30 feet thick. Along the southern border of the county it is 8 to 12 feet, and in Greene county, where the middle or dark portion has disappeared, it seldom exceeds 3 feet.

The coal beds in this interval are unimportant.

The Washington A coal bed (J. J. Stevenson, 1876), between the Blacksville and Middle Washington limestones, was supposed at the time it was described to be confined to three townships of southeast Greene county. There it is an alternation of coal and shale 3 to 4 feet thick and possessing no value. It is a fairly well marked horizon elsewhere, showing black shale at many places in eastern Greene and coal in two townships on the west side of the county, the only ones exposing its place. Occasionally one finds a coal streak in Washington county at varying distances below the Middle Washington limestone which may or may not be contemporaneous in part with the deposit of Greene county.

The Jollytown coal bed (I. C. White, manuscript, 1875; J. J. Stevenson, 1876), named from a village in southwest Greene county of Pennsylvania, is 25 to 40 feet below the Franklin (V) limestone in eastern and southern Greene, but is irregular in the northwest part of the county, where its place is reached again. It is distinctly present in Amwell and Franklin townships of Washington, into which it was traced from Greene county, and a blossom or thin coal marking this horizon was seen

in several other townships. Failure to recognize the Franklin limestone in this county led Stevenson to confound the Canton horizon with this at a number of localities. The bed is present in Fayette county of Pennsylvania, but it is not the Jollytown coal of Maryland, which is higher in the column. Some confusion has existed respecting the proper application of this name, due to omission of part of the section at Jollytown, so that in reading the text as published* one might easily imagine that Limestone V and Limestone IX of two sections there given may be the same; but the full measurements taken from the original notes as given on a succeeding page make the matter wholly clear. This coal bed is always thin, seldom even 2 feet thick, but it is apparently continuous under an area of several hundreds of square miles, as it is never absent where its place is exposed. It is certainly continuous southward into Monongalia and Wetzel of West Virginia, but it is absent from the published sections within Marshall of that state. There are two thin coal beds in southwest Greene within a vertical space of 55 feet, the Jollytown at about 50 feet below the Upper Washington limestone and the Boyd just above that limestone. The disappearance of the limestones makes it difficult to determine which of these beds persists. In the succeeding pages a bed at Bellair, Ohio, is taken to be the Jollytown; it is 183 feet above the Washington coal bed. At Moundsville the Upper Washington limestone is 244 feet above that coal bed, and at Bellair the interval should not be more than 210 feet. Evidently the same bed is at Baresville, in Monroe county of Ohio, and Liberty, in Washington county, at 149 and 140 feet above the Washington. Oil-well records give information respecting the distribution of the bed in the deeper parts of West Virginia, and its place is concealed in Doctor White's sections along the Ohio river.

The Canton coal bed is wholly insignificant and without interest except in respect to its distribution. It is confined to Washington county of Pennsylvania, where, in the central and western parts, one usually finds a thin streak of coal at 12 to 30 feet below the Upper Washington limestone. The thickness is usually less than 1 foot and the bed disappears westwardly in the West Virginia panhandle at little more than a mile from the state line. No trace of this deposit was seen in Greene county.

The variations in the interval between the Washington coal bed and the Upper Washington limestone resemble those observed in the interval below. The numerous elements of the section make the tracing comparatively simple. At the extreme northern exposure of the whole in-

* Pennsylvania reports, vol. K, p. 111.

terval, in Smith township of Washington, the beds are 110 feet apart. Along the west side of the county this increases to 140, 150, and 160 at the Greene county line; but thence the increase is more rapid, so that in southeastern Richhill township of Greene it is 240, and at a little southwest in Aleppo it is 308 feet; the same interval is found in Marshall county of West Virginia, 7 or 8 miles farther southwest. One finds the increase in a southeasterly direction, 110, 135, 140, and as one approaches the Greene county line, in Amwell of Washington, 180 to 190 feet. Where the beds are reached again, in Franklin of Greene, the measurement is 270, and in Perry, near the West Virginia line at the south, it is about 300 feet. Westwardly, in Ohio county of West Virginia, the interval is 140, and in the adjacent part of Washington county it increases south of west in 15 miles to 244 feet at Moundsville, and in 23 miles southward to 308 feet at Belton. What the conditions are beyond one may not assert positively, but if one may decide from the relations of the Jollytown coal bed, the interval decreases notably toward the southwest.

The variations in character of the rocks in this interval is important. The limestones are the chief features of the section in Washington county, especially in the central portion of the county; in all directions they become thin, so that in Marshall of West Virginia at the west all have disappeared except the Upper Washington; in Fayette, all are thin; southward, in West Virginia, all disappear quickly except the Lower Washington. Massive sandstone is rare in Washington and Greene, though occasionally one finds in those counties as well as in Fayette a massive rock underneath the Upper Washington. Other sandstones become noteworthy farther south until in Washington county of Ohio and the adjacent counties of West Virginia one finds the great sandstones quarried for grindstones and termed by I. C. White the Marietta sandstones (1903). He has found these beds more or less prominent in the southern part of the Dunkard area within West Virginia.

The next characteristic interval, that between the Upper Washington and Nineveh limestones, is followed with great ease within Pennsylvania. The Nineveh limestone, at the top, is 25 to 35 feet below the Nineveh coal bed, which underlies the massive Nineveh sandstone. The massive rock above has protected the underlying beds in the most important localities, so that there is little danger of error in identification of the Nineveh limestone. The lower limiting bed, the Upper Washington limestone, is equally well defined, not only by its associated beds, but also by its peculiar features.

The Ten-mile limestone, VII of volume K, is a persistent bed about 14 feet above the Upper Washington in central Washington county; but

the interval increases southwardly to 20, 30, and in central Greene county to 40 feet. The increase is less rapid southwestwardly, for it is only 27 feet in Richhill of northwest Greene. The place of this limestone is not reached north from the borough of Washington. It is thick in Washington, but in Greene it is rarely more than 3 feet, is usually earthy, and it disappears toward the southwest. The Rogersville limestone, VIII of volume K, must be regarded as confined to central Greene county, where it is 19 to 35 feet above the Ten-mile. Where last seen before passing under the higher beds, it is earthy, so that one is not surprised to find no traces of it in western Greene. A limestone is reported occasionally in five townships of Washington county at 65 to 80 feet above the Upper Washington, the place of the Rogersville. There are evidently many limestone lenses at this horizon.

The Jollytown limestone (I. C. White, 1891), IX*a* of volume K, is a persistent deposit in a small area. It seems to be continuous in western Greene and the adjacent part of West Virginia and it may be present in the extreme southwest corner of Washington county. Its place is concealed at all localities examined in Franklin, a central township of Greene, but the Rogersville is persistent there, as also farther east in Jefferson where a limestone is present at the proper distance above the Rogersville, as measured in Center township. This bed was seen in Perry township 9 miles south. The evidence is rather in favor of regarding this limestone, which Stevenson took to be the Nineveh, as at the Jollytown horizon. The interval from the Jollytown to the Upper Washington limestone decreases southwardly, in 12 miles, from 140 feet in Center township to 29 feet at Jollytown, on the West Virginia line; and this small interval prevails along the southern line, for near Belton and Board Tree, in Marshall of West Virginia, it is shown by Doctor White's sections to be only 30 feet. The maximum is in Center, for westward in Aleppo the measurement gives only 115 feet, while northwardly it decreases rapidly.

The Nineveh limestone (I. C. White, 1891), X of volume K, is 25 to 35 feet below the Nineveh coal bed which underlies the Nineveh sandstone. It remains in several townships along the southern line of Washington county, the most northerly point at which it has been recognized with certainty being about 30 miles south from the extreme northern outcrop of the Upper Washington. It was seen at every place in Washington and Greene exposing its place. It is equally well marked in West Virginia, where Doctor White has recognized it in almost every county, reaching its place as far south as Jackson county, beyond the Little Kanawha river. It is evidently the high limestone of Professor Andrews's

long sections in Monroe county of Ohio. The remarkable persistence of this limestone bed, so much in contrast with the limited extent of all other beds below, makes it not improbable that it may be that in the Maryland area which Doctor Martin has correlated with the Jollytown. The interval there is 238 feet above the Washington coal bed. The limestone in Pennsylvania and West Virginia is almost unmistakable, the color being a peculiar blue and the associated shales, black. It is often thin, but increases southwardly, so that beyond the Pennsylvania line it has sometimes 10 or 15 feet of limestone and calcareous shale, and at almost the last exposure in Jackson county at the south the mass is almost 30 feet.

The coal horizons are unimportant.

The Boyd coal bed refers not to a bed, but to a horizon. In the interval between the Upper Washington and Ten-mile limestones one finds oftentimes a coal streak, now almost on the lower limestone, again almost directly under the upper, and occasionally almost midway, the last condition being in localities where the interval between the limestone is greatest. The deposits can hardly be contemporaneous, but the interval is a small one and they may overlap in time. The name is taken from Boyd run, in Greene, the only place at which the coal is of workable thickness. A coal at this horizon is in West Virginia just south from the state line, where it rests on the Upper Washington. The term Pursley coal bed is used in the same way, to designate a coal horizon between Ten-mile and Rogersville limestones, an interval in which isolated deposits of coal occur at numerous localities.

The Dunkard coal bed (J. J. Stevenson, 1876), a thin but very persistent bed in western Greene, is absent from Washington and it was not recognized in the northern border of Greene county. It is not present in eastern Greene. The bed is rarely more than 2 feet thick, but is double and, like some of the lower beds, is associated with a plant-bearing shale. Though very thin, it is of much local importance, as it yields good coal. In the southwest corner of Greene, it is about 125 feet above the Jollytown coal. A trace of coal found by Doctor White on the Ohio river, in Tyler county, at about 100 feet above the bed already taken as the Jollytown, may be at the Dunkard horizon. Another coal bed, apparently that termed the Hostetter by Doctor White (1891), is in the interval between the Dunkard coal and Nineveh limestone, at about 40 feet below the latter. It is present in Springhill, Aleppo, Richhill, and Morris townships of Greene. A coal in this interval is shown in Wetzel of West Virginia.

The Fish Creek sandstone (J. J. Stevenson, 1876) is present at most localities just above the Dunkard coal bed. Sometimes it fills the whole interval to the Nineveh limestone. It differs from most of the Dunkard sandstones, in that it is well cemented and answers well for building stone. This is a characteristic feature for many miles southward in West Virginia.

The variations in the interval between the Upper Washington and Nineveh limestones deserve especial consideration. As has been remarked, the limiting beds are traceable with the utmost ease, and the connecting lines as well as the measurements are so numerous as to leave no room for doubt respecting the relations in by far the greater part of the area.

At the southwest corner of Washington county, Pennsylvania, these limestones are 150 feet apart; 5 or 6 miles east the interval is 180, decreasing to about 160 in 3 or 4 miles farther. If the highest limestone in Franklin of Washington, 5 miles northeast from the last, be the Nineveh, as supposed, the interval there is but 150 feet. In the northern townships of Greene this interval, 150 feet near the West Virginia line, increases gradually to about 180 at the most easterly measurement, say 15 miles away. These measurements are barometric, but they are checked by a well record near Nineveh, 12 miles east from the West Virginia line, where the Nineveh coal bed is 488 feet above the Waynesburg, making the distance from the Nineveh limestone about 450; so that the interval under consideration cannot be more than 150 feet. A high ridge crosses Greene county in a south-southwesterly direction from near Nineveh. Following the east side of this ridge from Nineveh into Center township, one finds a remarkable increase within 5 miles, for the measurement is

Nineveh limestone.	
Interval	120
Dunkard coal bed	2
Interval	35
Jollytown limestone	7
Interval	135
Upper Washington limestone.	

practically 300 feet, and showing the Pursley coal bed, Rogersville and Jollytown limestones, and the Dunkard coal bed, all of which seem to be wanting in the Nineveh region. On the other side of this ridge, 5 or 6 miles northwest, the interval is little more than 150 feet, with these beds wanting; but westward, in Jackson township, the Dunkard and

Jollytown are present, and still farther west Doctor White's Aleppo section shows the succession completely and the interval is 313 feet. But southwardly the decrease is rapid, for in southern Center, a direct measurement gives only 262 feet, and at a few miles farther, near the West Virginia line, it is only 208. At Belton, in Marshall of West Virginia, about 10 miles west from the last, the interval is 238. Eastward the Nineveh limestone is exposed in no section south from the northern tier of townships, but the Jollytown limestone seems to persist and the interval to it from the Upper Washington is 145 feet at, say, 15 miles east from the Center measurement and the general conditions are apparently as in Center; but in the southeastern part of the county the interval between these limestones is less than 100 feet, showing a decrease in that direction.

No detailed sections are available in West Virginia until the Ohio river is reached, where are the long sections by Professor Andrews and Doctor White, which show the Nineveh limestone 368 to 380 feet above the Washington coal bed. That interval at Belton, in Marshall county, is 551 feet. Using the Jollytown coal bed for comparison, the interval from the Upper Washington to the Nineveh is about 200 feet at New Martinsburg, in Wetzel county, and apparently the same in Tyler county, showing very gradual change in 40 miles southwestwardly.

The changes are particularly in the lower half of the interval and differ materially from those of the preceding intervals. That portion lying between the Fish Creek sandstone and the Ten-mile limestone appears very abruptly as one approaches central Greene from the north; its greatest thickness is in a narrow east and west strip across the central part of the county. Southwardly almost the whole interval between the Upper Washington and the Jollytown limestones disappears, and apparently it is almost wholly unrepresented southwestwardly in West Virginia. The contrast in conditions is almost as great as that between the Conemaugh and Monongahela.

The remaining beds of the Dunkard require only a brief reference, as the area in which they have been recognized in detail is very small.

The Nineveh coal bed (J. J. Stevenson, 1876) is double, seldom exceeds 2 feet, but, like the Dunkard, yields such good coal that it is mined by stripping and possesses not a little of local importance. It is persistent in southern Washington and Greene and in West Virginia to many miles beyond the state line. It underlies the Nineveh sandstone (I. C. White, 1891), which is persistent for at least 30 miles southwestward in West Virginia. This is a massive rock, very similar to the Fish Creek sandstone, overlying the Dunkard coal bed.

On the high ridge of central Greene there are several limestones which Stevenson designated by numbers. XI and XII are, in round numbers, at 80 and 160 feet above the Nineveh limestone and are persistent in the five townships of Greene county in which their place is exposed; they are concealed in the southwest townships of Greene and in the adjacent part of West Virginia. XI is always thin, but XII is from 8 to 15 feet thick and appears to be associated with much chert in Morris township of Washington county. This was not seen in place, but it is above XI on a hill which reaches almost to XII. A thin limestone at 30 feet higher underlies a coal blossom which is at the place of the highest coal in Professor Andrews's Baresville section, 150 feet above the Nineveh limestone, and the name has been assigned to it for that reason. Two higher limestones are present on this ridge, of which the upper is 275 feet above the Nineveh coal bed and about 30 feet below the Gilmore sandstone. It is exposed only in Center and Jackson townships of Greene, but it was found in a well in Gilmore township. It is evidently the limestone found in Wetzel township at about 100 feet below the Windy Gap limestone. This, which may be termed the Jackson limestone, seems to be clearly persistent along a line of more than 30 miles, beyond which information is lacking. It is a tough, impure rock containing some crystalline sphalerite and is associated with plant-bearing shales in Jackson township near White Cottage.

The Gilmore sandstone (J. J. Stevenson, 1876), 30 feet thick, caps the high knobs of southwest Greene, and it has been followed along the middle line of the trough for 40 or 50 miles by Doctor White. It is soft, somewhat incoherent, and is apt to weather into large cavities. At 30 feet higher is a black shale, which occasionally carries some coal, and Doctor White has called it the Windy Gap coal bed (1891). The Windy Gap limestone (I. C. White, 1891), 30 feet above the coal bed, is on two or three knobs within Greene county and in Monongahela and Wetzel to 10 miles south from the Pennsylvania line. It is a rather pure limestone and, like the Jackson, contains some sphalerite. The formation is capped by a massive sandstone seen occasionally in Marshall and Wetzel counties of West Virginia the highest stratum of the Paleozoic in the Appalachian basin.

Red shales in the interval between the Waynesburg and Washington coal beds find their chief development in what may be termed the "red area" of West Virginia and Ohio. The individual beds within Wood, Jackson, and Mason of West Virginia and Meigs of Ohio are from 25 to 100 feet thick. In Tyler, Doddridge, Ritchie, Wirt, and Calhoun of West Virginia, east Washington and east Monroe of Ohio, a bed is very

often found within 50 and another at about 100 feet below the Washington; a bed near the Waynesburg A is in Muskingum of Ohio and Harrison of West Virginia; but reds are unknown elsewhere, except at one locality in southwest Washington county of Pennsylvania, where a bed 10 feet thick is at 30 feet below the Washington. In geographical extent, the reds of this interval are inferior to the Tyler reds and far inferior to the Ritchie reds.

An expansion appears in the interval between the Washington coal bed and Upper Washington limestone. Well records are wanting in several counties within the "red area," but enough is known from surface observations to show that, as before, the chief importance is in that area. In Wood county of West Virginia red shale is present in some well or other at every foot of the interval, and in Washington county of Ohio the same statement is true for 150 feet above the coal. In those counties the beds are 50 to 100 feet thick. Reds are in the bottom 70 feet of the interval as far north as Wetzel and as far east as Harrison county, but they are wanting apparently in Marshall and in Belmont of Ohio. A very persistent deposit begins at 70 to 90 feet above the coal and is present in all of the counties named, including Marshall and Belmont, and a still higher deposit is shown at Moundsville, 45 feet thick and directly underlying the Upper Washington limestone. Its place is not reached in any recorded section farther north, but it is doubless represented farther south by some of the thin beds. No records are available for Monongalia and Marion counties of West Virginia, but in all probability these reds are there, for a well record just over the line in Greene county of Pennsylvania notes three beds in this interval, in all 50 feet; but elsewhere in Greene, Washington, and Fayette of Pennsylvania and eastern Marshall of West Virginia there appears to be no trace of reds in this interval except at three widely separated places, one in west central Greene, 2 feet, under the Franklin limestone, one in Perry township, 10 feet, at the Middle Washington horizon, and a third in southwest Washington, where a deposit 60 feet thick is divided by the Middle Washington. The reds of this interval have less extent than that of the Washington reds in the Conemaugh.

One riding over the counties of Ritchie, Wood, and Calhoun of West Virginia recognizes the great amount of red shale in the next interval, that reaching to the Nineveh limestone; but details are not accessible. Measurements of surface exposures would be worthless for comparison, owing to variability of the beds, and there are no well records, as the drillers see nothing worth recording in the dreary alternations of shale and sandstone. Doctor White mentions a "great mass" of reds under-

lying the Nineveh limestone in central Wood county, but the reds of this interval very soon become unimportant northward, for in Tyler of West Virginia and Washington of Ohio the total in three or four beds is not more than 40 feet, while in Wetzel all are insignificant, that under the Nineveh being only 5 feet; it is thicker in Monroe of Ohio, being 14 to 18 feet; but in Pennsylvania and Marshall of West Virginia reds are wanting everywhere in this interval except on the state line in Greene and Marshall, where thin deposits are near the Dunkard coal. Clearly, the reds of the Upper Washington-Nineveh interval are confined practically to the central part of the "red area."

Little can be said of the column above the Nineveh limestone. Reds in very thin beds were seen just above the Nineveh limestone in Monroe and Wetzel, but this deposit is apparently unknown elsewhere, except in southwest Washington of Pennsylvania, where it is spread through a vertical interval of 50 feet. Much red is in eastern Marshall, in the space of 180 feet above the Nineveh coal bed, and three beds, 11 feet thick in all, are in the same interval in southern Greene; but no other reds are reported from Greene county, except at one exposure where the Jackson limestone rests on a thick deposit.

It is evident that the reds of the Dunkard, outside of the "red area," are less important than are those of the Conemaugh, and that they can be compared only with the reds of the Monongahela. Their distribution is extremely irregular and in many cases the deposits seem to be due to local conditions of very limited extent.

EAST FROM THE ALLEGHENIES

A few acres of Dunkard rocks remain on Round knob, the highest point of the Broad Top area in Bedford county of Pennsylvania. There a coal bed, somewhat less than 275 feet above the Pittsburg, underlies 100 feet of concealed measures. Conditions west and south suggest that this coal bed is not far from the Washington horizon. Where exposed in 1881 it is 1 foot 4 inches thick, but Professor J. P. Lesley saw an opening in 1856 showing 7 feet of coal and shale. It seems to be almost in contact with a thick underlying limestone.*

Some isolated patches of Dunkard have been examined in the Georges Creek area of the Potomac basin in Maryland. The extreme thickness is in Allegany county, where about 400 feet remain. The sandstones, except the Waynesburg, are insignificant and the shales are mostly reddish green. The succession as given in the Maryland reports is:

* J. J. Stevenson: (T 2), pp. 59, 60, 249.

	Feet	Inches
1. Massive sandstone	10	0
2. Concealed	25	0
3. Jollytown limestone	Thin	
4. Concealed	15	0
5. Jollytown coal bed	2	2
6. Concealed	20	0
7. Upper Washington limestone	4	0
8. Concealed	80	0
9. Middle Washington limestone	2	0
10. Concealed	110	0
11. Limestone and shale	2	6
12. Washington coal bed	3	6
13. Concealed	10	0
14. Shales	63	0
15. Waynesburg A coal bed	2	0
16. Waynesburg sandstone	45	0
17. Waynesburg coal bed.		

The thicknesses are probably extreme, as separate sections have been combined to obtain the details. The correlations above the Washington coal bed are to be taken only as tentative; those which seem more probable have been given on a preceding page. The Washington coal bed retains the features characterizing it at western exposures, as appears from the diagrams given in the reports.*

EAST FROM THE MONONGAHELA RIVER, IN PENNSYLVANIA

No Dunkard beds have escaped erosion in the First and Second bituminous basins of Pennsylvania; but west from Chestnut Ridge to the Monongahela they are found in somewhat widely separated patches, at times embracing several square miles. The rocks belong to the lower portion of the column and are soft, so that exposures as a rule are very poor and the information is scanty.

In the Blairsville-Connellsville trough one finds traces of the Waynesburg sandstone at almost the northern extremity, near the Conemaugh river. Farther south, in Unity of Westmoreland county, that sandstone is 40 feet thick, and in Mount Pleasant the section reaches to what seems to be the Colvin limestone. South from the Youghiogheny river, in Fayette county, the Washington coal bed, 4 feet thick, is shown at one locality where the hills are high enough to catch the Upper Washington limestone. The Waynesburg sandstone is distinct to at least 14 miles south from the river, beyond which its place is not reached.

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* C. C. O'Harra: Allegany county, p. 129.
G. C. Martin: Garrett county, pp. 144, 145; vol. v, p. 258.
W. B. Clark et al.: Vol. v, pp. 312, 313, 314, 406, 407.

It is wholly probable that some portion of the Dunkard column remains within the Greensburg trough of northern Westmoreland, but no correlation of the imperfectly exposed beds can be made.

The lower beds of the Dunkard are present in western Westmoreland almost to the Kiskiminetis river at the north, but no exposures are noted until near the Fayette border at the south. The Washington coal bed underlies the Lower Washington limestone and varies from 5 to 9 feet, in the latter case having almost 8 feet of coal in 8 benches. It is 135 feet above the Waynesburg coal bed, and the Waynesburg A, 3 feet below the bright yellow Colvin limestone, is 55 feet above the lower coal bed. Small patches in northern Fayette occasionally show the Waynesburg A and Washington coal beds with the Lower Washington limestone, but the important area is farther south, in Redstone, Luzerne, and German townships, where one has surface observations supplemented by detailed shaft records. A massive sandstone was seen in Redstone, 330 feet above the Waynesburg coal and only a few feet above a thin coal bed correlated with the Jollytown. It is like that underlying the Upper Washington limestone at some places in Washington and much of Greene, so that the correlation is probably correct. The Washington coal bed in these townships, from 3 to almost 6 feet thick, is always multiple and yields poor coal, rich in ash and sulphur. The Lower Washington and Blacksville limestones are usually present, and the Colvin limestone, with the Waynesburg A coal bed below it, is always shown where its place is exposed. The Waynesburg sandstone is prominent, though sometimes replaced in part by sandy shale; ordinarily it rests on the coal, the Cassville shale having been removed.*

The irregularity of the coal beds and the ease with which one depending only upon imperfect road exposures may be deceived are shown by comparison of the Brier Hill and Lambert records, the former in Redstone and the latter in German township:

	Feet	Inches	Feet	Inches
1. Washington A coal bed, clay, sandstone........	18	9	13	0
2. Sandstone, shale, thin limestone..............	22	6	27	7
3. Coal bed	Thin		0	5
4. Clay, limestone, calcareous clay..............	8	5	9	2
5. Coal bed	3	0	2	3
6. Sandstone, shale, thin limestone..............	22	8	27	11
7. Washington coal bed..........................	4	0	2	5
8. Clay and sandstone	11	8		
9. Little Washington coal bed..................	3	0	31	11
10. Shale	25	0		

* J. J. Stevenson: (K 2), pp. 154, 178, 211, 226, 227, 229, 231, 259, 273, 356-359, 365, 366, 381.

		Feet	Inches	Feet	Inches
11. Coal	Waynesburg B	3	0	2	0
Sandstone, shale		7	10		
Coal, black shale		2	3		
12. Limestone and clay		3	0	50	9
13. Sandstone		47	0		
14. Colvin limestone and clay		9	0		
15. Waynesburg A coal bed and black shale		4	5	3	5
16. Clay, sandstone, shale, thin limestone		59	10	61	0

to the Waynesburg coal bed. The coal beds are approximately

	Feet	Feet
Waynesburg A	60	61
Waynesburg B	124	115
Washington	176	149

feet above the Waynesburg. The first coal above the Washington is reported from only one other locality in Pennsylvania. The Washington A at Brier Hill shaft has three coal layers in all, 2 feet 1 inch thick, but at the Lambert the three layers of almost equal thickness have 5 feet 7 inches. Southward the section does not reach to the Dunkard, but westward, toward the Monongahela river, the Waynesburg sandstone becomes very massive.

WEST FROM MONONGAHELA RIVER, IN PENNSYLVANIA

The Washington coal bed at its most northerly exposure in Allegheny county is 3 feet thick and 320 feet above the Pittsburg, with the Blacksville limestone 25 feet above it and 4 feet thick. At 4 miles west the coal bed is 75 feet above the Waynesburg, while 3 miles south, in Snowden township, the interval is 90 feet, and the Waynesburg A is seen at 50 feet below the upper bed.*

The Lower Washington and Colvin limestones appear first in Cecil township of Washington county, 8 miles south from the last locality, and at 8 miles west the Blacksville limestone, 20 feet thick, is 30 feet above the Washington coal bed, which almost directly underlies its limestone. Here the Little Washington as well as the Waynesburg A is seen and the Colvin limestone is 15 feet thick. The Waynesburg sandstone is represented only by sandy shale and the Cassville shale contains 4 feet of limestone. The Washington and Waynesburg coal beds are 85 feet apart, but at 4 miles northwest, in Smith township, this interval decreases to 65 feet, and the Upper Washington limestone, 6 feet thick, is only 110 feet above the Washington coal bed. This is the most

* J. J. Stevenson: (K), pp. 303, 306, 313.

northernly exposure of that limestone. Within a mile and a half toward the west the interval between the Washington and Waynesburg coal beds is reduced to 50 feet, and that from the Upper Washington limestone to the lower coal cannot be more than 160 feet. The Lower Washington limestone is 8 feet thick and the interval between the Washington coal and the Colvin limestone varies from 20 to 6 feet, the least interval being at the last northward exposure. Southwardly the intervals increase along the western border, and in southern Independence they become 158 and 100 feet. The Blacksville limestone is 20 to 30 feet thick in Cross Creek and Independence townships, where a massive sandstone underlies the Upper Washington. The Middle Washington limestone appears abruptly in Independence with a thickness of 20 feet, and there also one sees for the first time the Franklin limestone, 35 feet below the Upper Washington and directly underlying the Canton coal bed. The conditions are much the same in Hopewell east from Independence, where the limestones are present and thick, except the Colvin and Franklin. The Waynesburg sandstone is massive, but it has not cut away the Cassville shale, which carries some limestone here, as almost everywhere on this side of the county.

A thin coal bed marking the Boyd horizon was seen just above the Upper Washington limestone in Smith, but not in the other townships named, where only black shale was seen. The Jollytown coal bed appears first in Hopewell and Independence, where it is about 20 feet below the Franklin limestone. The Washington coal bed, 4 feet to 5 feet 6 inches thick and multiple, is 109 feet above the Waynesburg in southern Hopewell. The Waynesburg A, not seen in the townships along the West Virginia line, makes its appearance in Hopewell at 40 feet below the Washington.*

Farther east, in North Strabane, the Upper Washington limestone is 145 to 160 feet above the Washington coal bed, which is 110 to 120 feet above the Waynesburg, the intervals increasing southwardly. The Canton coal bed, very thin, seems to be continuous at 12 feet below the Upper Washington. The interval from the Canton coal to the Blacksville limestone is usually concealed here, as well as in Nottingham and Peters townships farther east, so that the Franklin and Middle Washington limestones are not reported. The other limestones of this interval are from 8 to 25 feet thick. The massive sandstone underlying the Upper Washington makes a "rock city" in Peters.

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* J. J. Stevenson: (K), pp. 269, 270, 281, 282, 283.
I. C. White: (K), pp. 229, 285, 288, 291, 292, 293, 294.

The Washington coal bed is thin and unimportant throughout. No trace of the Jollytown coal bed was observed in these townships, nor was the Canton seen east from North Strabane. The Waynesburg B, seen for the first time in North Strabane, and the Waynesburg A, with the Colvin limestone, are present in Nottingham as well as still farther east in Union, Carroll, Fallowfield, and Somerset. These coals are worthless.

The interval from the Upper Washington limestone to the Washington coal bed changes very slowly, being still 160 feet in Somerset, but that between the Washington and Waynesburg coal beds, only 120 feet in North Strabane, becomes 140 in Fallowfield and Somerset. The Cassville shale, carrying no limestone in these townships, is of irregular occurrence, often cut out by the overlying Waynesburg sandstone, which becomes massive and very prominent toward the Monongahela valley.*

In the neighborhood of Washington borough measurements were obtained in Canton, South Strabane, and Franklin townships, giving the following succession:

	Feet
1. Limestone, dark blue, Nineveh	Fragments
2. Concealed	10
3. Limestone	Fragments
4. Concealed	35
5. Limestone, light in color	5
6. Concealed	55
7. Limestone, light blue, Rogersville	3
8. Coal bed, Pursley	Blossom
9. Concealed	30
10. Limestone [Ten-mile]	5 to 10
11. Shale	2 to 5
12. Coal bed [Boyd]	Blossom
13. Clay, sandstone, shale	9 to 21
14. Upper Washington limestone	6 to 20
15. Concealed	30
16. Coal bed [Canton]	Blossom
17. Concealed	20
18. Coal bed [Jollytown]	Blossom
19. Concealed	15 to 25
20. Middle Washington limestone	6 to 20
21. Shales	10 to 15
22. Coal bed, Washington A	Blossom
23. Shales and thin limestones	40
24. Lower Washington limestone	23 to 33
25. Washington coal bed	4 to 7
26. Washington sandstone, clay, shale	12 to 17

* J. J. Stevenson: (K), pp. 212, 220, 228, 237, 238, 239.
I. C. White: (K), 218, 219, 224, 226, 227.

	Feet
27. Little Washington coal bed	1
28. Shale and clay	2 to 10
29. Limestone	2
30. Concealed	79
31. Cassville shale	21

to the Waynesburg coal bed. Fragments of the Franklin limestone were seen at one place in Franklin township, but elsewhere it is concealed. The Blacksville limestone, so prominent in most of the Dunkard area, has almost disappeared, being represented by a few streaks. The Waynesburg sandstone is somewhat indefinite and at best is only a sandy shale; the Cassville shale has limestone in the shaft at Washington, which is the most easterly appearance of the limestone. The interval from Upper Washington limestone to the Washington coal bed is 150 to 160 feet, and that from the Washington to the Waynesburg coal bed is 115 to 124, decreasing westwardly.

The conditions are very similar southward in Morris, Amwell, and West Bethlehem along the southern border of the county, except in increase of the intervals, that from the Upper Washington to the Washington coal becoming 180 and 190 as one approaches the Greene county line, and that from the Washington to the Waynesburg becoming 165 feet. The Boyd, Canton, and Jollytown coals are present, as are also the Ten-mile and Franklin limestones. A massive sandstone, 250 feet above the Upper Washington and very near the place of the Nineveh sandstone, remains in West Bethlehem as a rock city on the Hillsborough knob.*

Buffalo, Donegal, East and West Finley townships form the southwest corner of Washington county. In the former two, at the north, the exposed section reached to 76 feet above the Upper Washington limestone. The Ten-mile limestone is 6 feet thick 20 feet above the Upper Washington and 40 feet below another whose relations are very uncertain. Coal was seen at the Boyd horizon in one exposure, and a blossom at 10 feet above the Ten-mile may be taken as representing the Pursley horizon. The Canton coal bed, 20 feet below the Upper Washington, was seen in both townships, very thin and 6 inches to 2 feet above the Franklin limestone, which is 1 foot 6 inches to 7 feet thick. A thin coal bed at a little way below the Middle Washington limestone seems to mark the Washington A horizon, but no trace of the Jollytown coal bed was seen. The Washington coal bed is 6 inches to 9 feet thick and for the most part of little worth. Of all the limestones, only the Colvin is absent.

* J. J. Stevenson: (K), 181, 184, 185, 188, 190, 241-244, 247, 248, 250, 251, 252.
I. C. White: (K), pp. 184, 187, 201.

Here, for the first time, red beds are seen in the Dunkard, there being in Donegal a mass, about 60 feet thick, resting on the Blacksville limestone and extending above the Middle Washington. At another exposure a purely local bed, 15 feet thick, is at the place of the Franklin limestone.

East and West Finley adjoin Greene county and the latter extends to the West Virginia line at the west. In Morris township the Upper Washington limestone is almost constantly in view from the east side of the township until within about half a mile of the East Finley line. There the Nineveh sandstone is 180 feet above the Upper Washington, and fragments of the Nineveh limestone were seen 35 to 40 feet lower, while at a little way farther west the Nineveh coal bed was seen under the sandstone. Chert appears in great abundance above the Nineveh sandstone, but it was not found in place; it seems to belong somewhere near the Limestone XII.

Crossing into East Finley and descending to Hunter's fork of Wheeling creek, one quickly reaches the Upper Washington limestone at little more than 150 feet below the Nineveh limestone, and at half a mile farther there is a coal bed 1 foot 6 inches thick and about 50 feet above the lower limestone. This seems to be not far from the Pursley horizon, but, in view of the changing intervals southwardly, one is hardly justified in making the correlation at present. The Middle Washington and Blacksville limestones are exposed at a little way farther and remain in sight to the west side of the township. The rapid fall of the stream in West Finley brings the lower rocks into the section, and the Waynesburg coal bed is reached at a considerable distance east from the state line. Exposures in the Finley townships are for the most part incomplete; the limestones are numerous and evidently not all of them are persistent. It seems to be clear that in preparing his report on Greene and Washington counties Stevenson erred in some of the correlations.

The highest limestone observed in place is coarse, dark on fresh fracture, and weathering with a rough surface. It is the bed numbered XI. At the West Virginia line it is 211 to 220 feet above the Upper Washington and it is exposed frequently on the west side of West Finley; it is reached again in the northwest part of the township and the adjacent part of East Finley, where the interval is 234 to 240 feet and the limestone rests on 50 feet of red shale, the Nineveh sandstone being absent. As in the case of the lower interval, this decreases eastwardly, so that on the east side of East Finley it is 200 feet, and at a mile or two farther east, in Morris, Doctor White found it 195 feet above the Upper Washington. The bed varies from 6 to 8 feet and gives a good strong

lime for the farmer. Fragments of a higher limestone, XII, were seen 50 feet above XI near the West Virginia line, but its place was not reached elsewhere in Washington county.

The Nineveh limestone, 145 to 153 feet above the Upper Washington near the West Virginia line, is reached at many places in these townships. The interval increases eastwardly to 180 feet on the border of East and West Finley, but farther east it decreases to 160. The rock is coarse, dark, and weathers blue and rough, though some portions become yellow. A third limestone, rarely exceeding 2 feet 5 inches, is very persistent at 103 to 123 feet above the Upper Washington. It may be equivalent to a limestone seen in the western part of Greene, but it is not safe to make any correlation of these limestones in this variable interval—at least until more detailed information has been secured.

The Upper Washington is 15 to 20 feet thick, and the Franklin, 30 to 40 feet lower, is a persistent dark limestone 20 to 30 feet above the Middle Washington. The Blacksville and Lower Washington appear wherever their places are exposed, but they vary greatly in thickness. The coals are wholly unimportant, and nothing to represent the Boyd, Jollytown, Waynesburg A or B was seen. The Waynesburg is the only prominent sandstone. A shale, apparently equivalent to the Cassville, overlies the Waynesburg coal bed at many places, but it carries no limestone.*

Passing over into Greene county, one soon reaches an area retaining the highest members of the Dunkard formation. A high ridge separating Wheeling and Fish creeks at the west from Ten-mile and Dunkard creeks at the east passes from Morris and East Finley of Washington county into Morris, Richhill, and Center of Greene. From this ridge in Greene long, irregular "hogback" ridges pass off into the townships of Jackson, Aleppo, Gilmore, and Springhill and thence into West Virginia, most of them capped by the Gilmore sandstone, and occasionally one shows some higher rocks. The section shows great variation in western Greene.

A principal fork of Wheeling creek heads up against this ridge in Aleppo township and flows northwest into Richhill. The succession along this stream as ascertained by Doctor White, somewhat condensed from the original notes, is:

* J. J. Stevenson: (K), pp. 192, 193, 194, 196, 199, 253, 256, 259, 260, 261, 264, 265, 266.
I. C. White: (K), pp. 198, 200, 201.

	Feet	Inches
1. Limestone [Windy gap]	4	0
2. Shale	25	0
3. Black shale [Windy Gap coal bed]	2	0
4. Shales	30	0
5. Gilmore sandstone	30	0
6. Concealed	300	0
7. Nineveh coal bed	1	0
8. Shales	25	0
9. Limestone and black shale [Nineveh]	8	0
10. Shale and sandstone	40	0
11. Coal bed [Hostetter (?)]	1	2
12. Brecciated limestone	2	0
13. Sandstone and concealed	30	0
14. Light-colored limestone	8	0
15. Shales and Fish Creek sandstone	70	0
16. Impure coarse limestone	2	0
17. Reddish shale	15	0
18. Dunkard coal bed	2	0
19. Limestone IX*b*	1	6
20. Sandstone	25	0
21. Limestone, coarse [Jollytown]	2	0
22. Red shale	10	0
23. Blue shale, flaggy sandstone	30	0
24. Red shale	4	0
25. Shales and sandstones	71	0
26. Upper Washington limestone	8	0
27. Sandstone and shale	40	0
28. Limestone, coarse [Franklin]	2	0
29. Red shale and sandstone	60	0
30. Shale and massive sandstone	75	0
31. Limestone, Middle Washington	2	0
32. Shale, clay	15	0
33. Coal bed [Washington A]	1	6
34. Shale	10	0
35. Limestone, light, good [Blacksville]	6	0
36. Shale and sandstone	30	0
37. Black shale, brecciated limestone, Lower Washington	6	6
38. Washington coal bed	3	6

The great gap between the Nineveh coal bed and the Gilmore sandstone is concealed throughout southwestern Greene and apparently in most of the West Virginia area; but it is shown more or less in detail within Morris, Richhill, and Center of Greene. The first two adjoin Morris and the Finleys of Washington; Center is south from Morris and eastern Richhill and contains the highest rocks, just failing to catch the Gilmore sandstone. The sections above the Nineveh limestone are:

					Feet	Inches
1. Jackson limestone					Fragments	
2. Red beds, sandstone					80	0
3. Limestone					5	0
4. Sandstone	Not measured		Not measured		40	0
5. Baresville coal bed	Blossom		Blossom		Concealed	
6. Shale	0	0	3	0		
7. Limestone	0	8	3	0	30	0
8. Shale	30	0	30	0		
9. Limestone XII	13	0	12	0	8	0
10. Sandstone, concealed	80	0	90	0	80	0
11. Limestone XI	2	6	2	11	2	6
12. Nineveh sandstone	42	0			35	0
13. Nineveh coal bed	1	0	78	0	1	8
14. Sandstone, shale	36	0			36	0
15. Black shale	1	0			1	0
16. Nineveh limestone	2	0	6	2	2	0

Thus far the sections are practically in accord. The highest limestone in Center, about 275 feet above the Nineveh coal bed, is the same with a limestone found in Jackson township at 30 feet below the Gilmore sandstone. It has been seen also in Springhill. No trace of the Baresville coal was seen in Center township. The Nineveh coal and sandstone, concealed in southeast Richhill, are shown at many places in Morris, Center, Jackson, and Aleppo. The coal is always thin, but is so good that it is mined at many places by stripping.

Below the Nineveh limestone to the Washington coal there is much variation in the sections. This portion, ill exposed in Morris and Richhill, is well shown in Center. A direct measurement in southeast Morris shows the interval between the Nineveh limestone and the Upper Washington limestone to be certainly not more than 160 feet, and the record of a boring in the central part of the township confirms this by giving the interval between the Nineveh and Waynesburg coal beds as 488 feet, or about 300 feet less than in Aleppo township. A coal bed, possibly the Hostetter, is reported in this well at 63 feet below the Nineveh coal, and in southeast Richhill its blossom was seen at 20 feet below the Nineveh limestone. The Ten-mile limestone is present, but the Rogersville seems to be wanting in Morris; one of these is present in Richhill, but which one was not determined. A direct measurement in southeast Richhill gives 150 feet as the interval between the Nineveh and Upper Washington limestones, showing that the condition is practically the same as in Morris.* But at 3 or 4 miles southward, in Center township, one finds the increased interval shown in Doctor White's Aleppo section,

* It should be remembered that the measurements are barometric throughout.

which prevails in Center, Jackson, and Aleppo. The section in western Center is:

	Feet	Inches
1. Nineveh limestone	2	0
2. Shale, sandstone, concealed	70	0
3. Fish Creek sandstone	50	0
4. Dunkard coal bed	1	8
5. Limestone 1 x 6	1	6
6. Sandstone, shale	35	0
7. Jollytown limestone, shale 1 x *a*	10	0
8. Shale, sandstone, concealed	100	0
9. Ten-mile limestone	2	0
10. Shale, sandstone	35	0

to the Upper Washington limestone. The Rogersville limestone is here, but concealed where the measurement was made. The Pursley coal bed, underlying the Rogersville limestone, is shown at numerous places and is mined on Pursley creek, where its thickness is 20 inches. The interval between the Nineveh and Upper Washington limestones is about 300 feet in northern Center, but in southwest Center it is about 260 feet and the Ten-mile limestone seems to be replaced by red shale. The Rogersville limestone disappears westwardly, becoming only calcareous shale near the line of Jackson township.

In Jackson township the Dunkard coal bed is only 100 feet below the Nineveh limestone, as it is also at an exposure in western Center; but in Aleppo that interval is 168 feet and one finds there at 40 feet below the limestone a thin coal bed, apparently the same with that in Morris and Richhill, at 20 to 24 feet, and perhaps the Hostetter bed. The place of this bed is concealed at the Jackson and Center localities. The Dunkard coal bed is constant in Center, Jackson, and Aleppo, but seems to be wanting in Morris and Richhill. It is thin, not exceeding 2 feet, in two nearly equal benches, separated by 1 to 3 inches of clay. The coal is good and is mined by stripping at many places. The little limestone, IX*b*, is always present with the coal, and the Jollytown limestone is equally persistent in Center, Jackson, and Aleppo, but it has not been recognized certainly in either Morris or Richhill. Its thickness is greatest in western Center; it is thinner and more shaly in Jackson, and is thin where last observed in western Aleppo. The interval from the Jollytown to the Upper Washington decreases westwardly from 137 feet in Center to 115 in western Aleppo. The Ten-mile limestone and Boyd and Pursley coals are evidently wanting in Aleppo near the West Virginia line.*

* J. J. Stevenson: (K), pp. 153, 154, 155, 157, 158, 159, 160-162, 172-174.
I. C. White: (K), pp. 161-163.
J. F. Carll: I 5, p. 308.

The section below the Upper Washington limestone is not reached in Morris or Jackson, but is shown in northwestern Aleppo, in western Richhill, and for the greater part in eastern Center, the distance between the outcrops of the Washington coal bed being about 12 miles. The interval between the Upper Washington limestone and the Washington coal bed is about 300 feet in Aleppo, where one finds the Franklin, Middle Washington, Blacksville, and Lower Washington limestones, all thin and more or less brecciated. There is no trace of coal at the Canton or Jollytown horizon, but the Washington A is seen in the Aleppo section at 52 feet above the Washington. In southern Richhill the Washington limestone rarely becomes 2 feet, while the Franklin, 20 feet below it, is 6 feet thick and brecciated; this great thickness led to mistaking it for the Upper Washington. The other limestones are insignificant. The Canton horizon carries no coal, but a thin streak marks the Jollytown. The interval between the Upper Washington and the Washington coal bed is about 230 feet in southern Richhill, but decreases northwardly until, near the Washington County border, it is not more than 160 feet. The Washington coal bed, seen always where its place is exposed, varies little from 3 feet 6 inches and is double, with a thick clay parting. The Waynesburg coal bed is reached in western Richhill, where the interval to the Washington coal is 130 feet, as ascertained by direct measurement in the northwest corner. This is much smaller than at localities farther east along the Washington County border where the coal is reached again. The insignificant Waynesburg A and B are both present, but the Colvin limestone is absent. The Waynesburg sandstone is massive and ordinarily rests on the Waynesburg coal bed.*

Following the section eastward along Ten-mile creek, across Center, Franklin, and Jefferson townships, one reaches the bottom of the column in Jefferson. The Rogersville limestone is a constant member into Jefferson, where it is 70 feet below a thick limestone which Stevenson took to be the Nineveh, but which on a preceding page has been correlated at least tentatively with the Jollytown. The earlier correlation may prove to be the true one, as the limestone is more like the Nineveh than the Jollytown, and the interval to the Upper Washington is nearly the same as at 5 or 6 miles farther north; but the persistence of the Rogersville limestone and its relations to the higher limestone, nearly the same as in western Center, seem to justify the tentative correlation with the Jollytown—the more so since the Pursley coal is persistent into Jefferson. The Ten-mile limestone is present everywhere along this

* J. J. Stevenson: (K), pp. 168-171.
I. C. White: (K), p. 163.

line to the most easterly exposure of its place. The Upper Washington is 270 feet above the Washington coal bed at Waynesburg, and an almost direct measurement by Doctor White in Jefferson 6 or 7 miles east makes the interval 254 feet. The Franklin limestone is always present at 30 to 35 feet above the Jollytown coal bed, which rarely exceeds 1 foot, but is always present. The Middle Washington limestone is absent, but the Blacksville and Lower Washington persist, though they rarely are more than 3 feet thick. The Waynesburg A and B coal beds seem to be continuous and the Colvin limestone is prominent. The Waynesburg sandstone, shown in Franklin and Jefferson and thence eastward to the Monongahela river, is sometimes 75 feet thick, more or less shaly or flaggy above, but massive and at times is slightly conglomerate below. The Cassville shale, carrying no limestone, is somewhat irregular in occurrence, but at several places is rich in plant impressions. The interval between the Washington and Waynesburg coal beds is 173 feet in eastern Franklin, and the greatest interval is 180 feet on the eastern edge of the county.

Washington and Morgan townships are north from Franklin, on the Washington county border. The Middle Washington was seen in the former at 98 feet below the Upper Washington, and a thin coal bed, perhaps at the Jollytown horizon, is at 83 feet below the latter limestone. A direct measurement between the Nineveh and Upper Washington limestones in Morgan gives 180 feet. This is 2 miles south from Ten-mile village, in Amwell of Washington county, and the Nineveh limestone was seen at many places along the northern border where there is a coal bed at 50 feet below it. A dark limestone, probably the Ten-mile, is 40 feet above the Upper Washington, and the Boyd coal bed, 30 inches thick, 15 feet above the Upper Washington, is mined on Boyd run, in Washington township. The Franklin limestone and the Jollytown coal bed persist, but the Washington coal bed and the other limestones are insignificant. The Waynesburg A and B and the Colvin limestone are here and the Washington coal bed is 160 feet above the Waynesburg.*

The southern townships from the Monongahela river westward along the West Virginia border are Dunkard, Perry, Wayne, Gilmore, and Springhill. In the first the exposed section reaches to little above the Washington A coal bed, which is very thin. The Waynesburg sandstone is prominent and at many exposures rests on the Waynesburg coal, but occasionally the Cassville shale, carrying no limestone, is present, 3 to 7 feet thick and crowded in the lower portion with fine impressions of

* J. J. Stevenson: (K), pp. 133, 134, 139, 141, 143, 145, 146, 149, 151, 152.
I. C. White: (K), pp. 138, 139.

plants. The Waynesburg A and Washington coal beds are both thin, and the latter is 160 feet above the Waynesburg at the only locality for direct measurement. The section is longer in Perry township. The Waynesburg passes under Dunkard creek at 8 miles west from the Monongahela, and at barely 3 miles farther west, where the Waynesburg A has passed under this succession, was found:

	Feet	Inches
1. Franklin limestone	Fragments	
2. Concealed	35	0
3. Jollytown coal bed	Blossom	
4. Shale, mostly	90	0
5. Limestone, sandy [Middle Washington]	4	6
6. Sandstone, mostly	75	0
7. Washington A coal bed and shale	3	0
8. Shale	20	0
9. Limestone III [Blacksville]	3	6
10. Sandstone	40	0
11. Shale	3	0
12. Lower Washington limestone	1	6
13. Shale and concealed	5	0

to the Washington coal bed, of which only the blossom was seen. The interval between the Franklin limestone and the Washington coal bed is about 280 feet; in Jefferson township, 9 miles east of north, it is 220 and in Franklin township, 9 miles west of north, it is 240 feet. The Jollytown coal bed is very thin, not more than 6 inches. Doctor White has published a section obtained two miles farther east, on Colvin run, in which the Franklin limestone is 10 feet thick and 35 feet above the Jollytown coal bed, which is 1 foot 6 inches; the Franklin is 281 feet above the Washington coal bed. He finds a limestone 9 feet thick at 135 feet above the Franklin, which is evidently the same with that seen in Jefferson. As at that locality, the rock resembles the Nineveh in several features, but the lessening interval in this direction seems to be related to the conditions seen in western Wayne and in Gilmore, so that on a preceding page this highest limestone has been referred tentatively to the Jollytown horizon. In this section Doctor White finds 10 feet of red shale very near the place of the Middle Washington limestone. The Washington A coal bed, seen at several places here, as well as in Whitely township, at the north, is 2 to 4 feet thick and so much broken by shale as to be unimportant. The limestones are all thin and even the Colvin is irregular, being only 3 feet on Colvin run. The Washington coal bed, 5 feet 8 inches thick, is triple and its coal is poor.

Doctor White measured a section on Dunkard creek, in Wayne township, which is almost the same with that obtained by Stevenson in Perry.

The Jollytown coal bed is 25 feet below the Franklin limestone and 110 feet above the sandy Middle Washington. The Washington A coal bed, 4 feet 3 inches of coal and shale is 85 feet lower and 73 feet above the Washington coal. The Upper Washington limestone is not exposed in this township except on the Gilmore border, but the Ten-mile limestone was seen in the northern portion and the Nineveh limestone is on the ridge at the line of Center township. Exposures are very bad in the greater part of this township.*

Ascending Dunkard creek, one finds the lower rocks passing under, so that at the line of Gilmore township the lowest rocks visible are only 56 feet below the Jollytown coal bed. There one has Doctor White's measurement:

	Feet
1. Shale	20
2. Franklin limestone	2
3. Shale	24
4. Jollytown coal bed	1
5. Shale, sandstone, fully exposed	56

with 2 feet of red shale at 30 feet below the Jollytown coal bed. This layer was not seen in Wayne township. The Jollytown coal bed, though very thin, yields good coal and is stripped at many places. It is in the road at Jollytown, on the east side of Gilmore. Some difficulty was encountered in making the section above the Franklin limestone, but the line in Gilmore and Springhill was revised very carefully by Stevenson and White, and Doctor White's measurements appeared to be very close to the truth. Since that time they have been confirmed by records of well borings in Marshall county of West Virginia just beyond the west line of Springhill township. Doctor White's section, not published in full in volume K, extends from a high knob in the middle of the township to Jollytown. As recorded in the note book, the lower portion is:

	Feet	Inches
1. Nineveh coal bed	1	2
2. Shales	25	0
3. [Nineveh] limestone and shale	7	0
4. Concealed	140	0
5. Dunkard coal bed	1	2
6. Limestone IX*b*	2	0
7. Shales	25	0
8. Limestone IX*a* [Jollytown]	1	6
9. Shale and sandstone	28	0
10. Coal bed [Boyd]	1	1

* J. J. Stevenson: (K), pp. 99, 104, 105, 153, 155.
I. C. White: (K), pp. 100, 106, 107, 108. U. S. Geol. Survey Bulletin, no. 65, p. 23.

	Feet	Inches
11. Dark shale	0	6
12. Upper Washington limestone	4	0
13. Sandstone	15	0
14. Shale	10	0
15. Impure limestone	1	0
16. Shale	10	0
17. Limestone [Franklin]	2	0
18. Shales	25	0
19. Jollytown coal bed	1	10

The interval between the Upper Washington and Franklin limestones is 36 feet. The section from the Dunkard coal bed to the Upper Washington limestone is shown at a mile and a half above Jollytown. If the limestone, Number 12, be the same with that seen at Jollytown, which seems to be practically certain, the interval between the Jollytown coal bed and the Jollytown limestone is 74 feet less than the interval in eastern Perry, 114 feet less than in Jefferson township. The interval between the Dunkard and Nineveh coals was not obtained by direct measurement; it is 172; at White Cottage, 6 miles north, in Jackson, it is 127; but in Aleppo, 8 miles northwest, it is 200 feet. The Gilmore sandstone is reached at the head of Dunkard creek, 30 feet thick and 30 feet above the Jackson limestone. The whole interval to the Dunkard coal bed, 300 feet, is without detailed exposures. These high rocks are reached on the divide between Dunkard and Fish creeks, over which one crosses into Springhill township.

Fish creek descends rapidly toward the west, so that within a mile one is below the Nineveh limestone. Everything between the Gilmore sandstone and that limestone is concealed in by far the greater part of the township, but there are frequent exposures of lower beds. The interval between the Nineveh limestone and Dunkard coal bed, measured directly at several places, varies from 120 to 150 feet, being greatest near the West Virginia border at the west. In the eastern part of the township a coal bed, 1 foot 1 inch thick, is at 45 feet below the Nineveh limestone and 80 feet above the Dunkard coal bed, and at 30 to 40 feet lower is an impure limestone. The coal bed is probably that termed Hostetter by Doctor White. Toward the west side of the township the Fish Creek sandstone, overlying the Dunkard coal bed, becomes continuous with a higher sandstone and extends almost to the Nineveh limestone, replacing the other beds. The Nineveh limestone retains its thickness to the western line, but becomes earthy. The Jollytown limestone is rarely exposed and it seems to be quite impure. As seen at one place, it is 6 feet thick and 165 feet below the Nineveh. A trace of

coal at 50 to 60 feet below it may be at the Jollytown horizon, as fragments of brecciated limestone are at a little way above it, and a thin coal bed at about 60 feet below the Dunkard may be at the Boyd horizon, which carries coal at a little way south in West Virginia.*

THE NORTHERN PANHANDLE OF WEST VIRGINIA

Passing westward into the northern panhandle of West Virginia, one finds information respecting the Dunkard in Marshall and Ohio counties, adjoining Greene and Washington. The lower part of the formation undoubtedly extends farther north into Brooke county. At a few miles east from Wheeling, in Ohio county, the Middle and Lower Washington limestones, each 20 feet thick, are 90 and 6 feet above the Washington coal bed, which is only 1 foot 3 inches thick. The Washington and Waynesburg coal beds are 96 to 104 feet apart, the Waynesburg A is 50 feet above the Waynesburg, and the Cassville shale carries 4 feet of limestone. The section is very like that 5 or 6 miles east, in Washington county. Doctor White finds the Washington coal bed 3 inches to 2 feet 6 inches at Wheeling, where it is 100 feet above the Waynesburg.

Doctor White's long section at Moundsville, 11 miles south from Wheeling, reaches upward to what appears to be the Upper Washington limestone, 224 feet above the Washington coal bed. That coal bed is 105 feet above the Waynesburg. A thin limestone, 53 feet below the upper coal, is at the place of one seen at Wheeling under Waynesburg A, but that coal bed is concealed. The Cassville shale contains 2 feet of limestone and the Waynesburg sandstone is replaced by shale. Five miles farther down the Ohio river the Washington coal is 5 feet thick. Thick limestones are above the Washington coal bed, but it is difficult to correlate them. Red beds, 10, 45, and 45 feet, are at 94, 139, and 199 feet above the coal, the last underlying the limestone taken to be the Upper Washington. Bellton, in Marshall county, is 15 miles southeast from Moundsville and is on Fish creek, about 2 miles west from the Pennsylvania line. There one has Doctor White's section, which confirms the measurements in the southern tier of townships in Greene county. Somewhat condensed they are:

	Feet	Inches
1. Windy Gap limestone	5	0
2. Shales	30	0
3. Windy Gap coal bed	Blossom	
4. Shales, sandstones, concealed	275	0
5. Limestone [XI (?)]	3	0
6. Shales, concealed	20	0

* I. C. White: (K), pp. 112, 113, 114.

	Feet	Inches
7. Nineveh coal bed	1	0
8. Shale, sandstone	35	0
9. Nineveh limestone and shale	10	0
10. Shale, sandstone, concealed	115	0
11. Limestone and thin coal bed	0	9
12. Shale, sandstone, concealed	40	0
13. Coal bed	1	0
14. Shales, concealed	30	0
15. Dunkard coal bed	1	3
16. Limestone IX*b*	5	0
17. Shales	13	0
18. Jollytown limestone	2	0
19. Shales and sandstone	30	0
20. Coal bed [Boyd]	0	8
21. Upper Washington limestone	5	0
22. Shale, sandstone	42	0
23. Fireclay [place of Jollytown coal bed]	7	0
24. Shales, sandstones	54	0
25. Coaly shales	9	0
26. Sandstones, shales	196	0
27. Washington coal bed	6	0
28. Shales, sandstones, thin limestone	140	0

to the assumed place of the Waynesburg coal bed. The portion below the Upper Washington limestone is taken from the record of an oil boring. Here one is at the extreme southeast corner of the county.

The Nineveh coal bed is, in round numbers, 230 feet above the Dunkard; at Board Tree, 3 miles southeast, this interval is 203, and in Gilmore township of Greene only 172 feet. The Jollytown limestone is 348 feet above the Washington coal bed, the loss as compared with central and eastern Greene being due to disappearance of most of the rocks between the Jollytown and Upper Washington. The interval, Washington to Waynesburg, has increased from 105 at Moundsville to 150 feet at Board Tree. All of the coals have become insignificant; the Boyd horizon still carries some coal, but the Jollytown as well as Washington A, Waynesburg A and B is either absent or so thin as to be overlooked by the drillers. The higher limestones have become insignificant and those between the Upper Washington and the Washington coal bed have disappeared.

Doctor White has preserved many records of oil borings in the southern part of Marshall county. At Cameron, 5 miles northwest from Bellton, the Waynesburg coal bed is 336 to 345 feet above the Pittsburg; a coal bed, 60 to 70 feet higher, is at the place of Waynesburg A, and a third, at 321 feet above the Waynesburg, seems to be at the place

of the "coaly shales" in the Bellton record. The Washington coal does not appear in any records here. In Meade district, farther west, where the Waynesburg is 280 to 290 feet above the Pittsburg, the Washington is 110 to 120 feet higher and the highest bed of the Cameron wells is 247 to 255 feet above the Waynesburg coal bed.*

OHIO

In the northern part of Jefferson county, Ohio, one finds near Knoxville a high knob retaining 78 feet of red and olive shales, above the Waynesburg coal bed, but the locality is too far away from any other exposure to admit of correlation. Farther south, in Mount Pleasant township, 110 feet of Dunkard remain, for the most part ill exposed; but in that as well as Smithfield township the Waynesburg A, evidently very thin, is at 50 feet above the Waynesburg, the interval being filled with sandstone, while sandy shale overlies the upper bed. Limestone is wholly absent. In Belmont county, 7 miles southeast, an imperfect section obtained almost opposite Wheeling shows the Washington coal bed at 95 feet above the Waynesburg and 4 to 6 feet thick. The Cassville shale, 9 feet 6 inches thick, has 3 feet of limestone on top underlying 15 feet of Waynesburg sandstone. A section by Mr Henry Newton, at 1 mile farther down the river, shows a limestone outcrop at 30 feet above the Washington, and at 90 feet there begins a mass of shaly sandstone streaked with red shale. In the northern part of the county the Waynesburg A, 1 to 2 feet thick, is shown frequently at 40 feet above the Waynesburg. The same coal is reached at one place in southeast Harrison, where it is 50 feet above the Waynesburg, the interval being filled with sandstone.

The section is longer in southern Belmont. Professor Brown's carefully leveled section was obtained at Bellair, 4 miles below Wheeling. It is:

	Feet
1. Coal bed [Jollytown]	2
2. Concealed, shale, sandstone	144
3. Limestone	7
4. Coal bed [Washington]	2
5. Concealed, mostly shale	64
6. Coal bed [Waynesburg A]	Blossom
7. Concealed	6
8. Limestone	2
9. Shale, thin limestone	45
10. [Waynesburg] coal bed	2

* J. J. Stevenson: (K), p. 266, and unpublished notes.
I. C. White: U. S. Geol. Survey Bulletin, no. 65, pp. 25, 26, 27. Catalogue of West Virginia University for 1883-1884, pp. 55, 59, 61, 63. Geology of West Virginia, vol. ia, pp. 215, 216, 217, 219, 221, 222.

Waynesburg A is 53; Washington, 117, and Jolleytown 303 feet above the Waynesburg coal bed, the Jollytown being 183 feet above the Washington. There are no exposures above this highest coal bed. If the highest limestone in Doctor White's Moundsville section be the Upper Washington—and the decreasing intervals at Cameron and in Meade seem to leave no room for doubt respecting the correlation—Number 1 of Professor Brown's section must be the Jollytown coal bed.

Mr Newton's section at Wegee, 3 miles south from the Moundsville section, reaches to a limestone at 18 feet above the Washington coal; the interval, Washington to Waynesburg, is 117 feet; the place of Waynesburg A is concealed, but there is a limestone, 39 feet above the Waynesburg, answering to number 9 of the Bellair section. Doctor White obtained a measurement below this, in the river hills, and found the Washington and Waynesburg 120 feet apart, with the interval almost wholly concealed. Few of the sections away from the river go above the Waynesburg, but one in Washington township, 8 or 9 miles back, shows the Waynesburg A at 46 feet above the Waynesburg, while at Barnesville, on the west side of the county, the interval is 42 feet and the thin limestone is 4 feet below the coal. Midway between Bellair and Barnesville the interval is 53 feet, as at Bellair, filled mostly with shale, red in the bottom, 2 feet 6 inches. The place of the Washington is seldom exposed, but the blossom was seen occasionally at 100 feet above the Waynesburg.*

Information respecting Muskingum, Noble, and Morgan counties along the western outcrop is scanty. The Dunkard is wholly without economic interest and few of the measured sections extend above the Uniontown coal bed. In southeast Muskingum a limestone, 2 feet thick, is 101 feet above the Uniontown and thick red beds at 10 feet higher, but no coal is shown. The Waynesburg A is mentioned at two places in Morgan county and has been opened at one where it is double, the benches, 16 and 24 inches, separated by 8 inches of shale. It is about 100 feet above the Uniontown. The Waynesburg sandstone is certainly here being the second conglomerate of Professor Andrews. No sections by Andrews in Noble county go above the Uniontown, but he notes the occurrence of Waynesburg A in the southeast corner. Professor Brown speaks of a few coal blossoms, one in Marion at 113 feet above the

* E. B. Andrews: Vol. ii, pp. 546, 554, 555, 567.

J. J. Stevenson: Vol. iii, Jefferson, pp. 760, 767; Belmont, pp. 271, 274, 277, 280; Harrison, p. 202.

H. Newton: Atlas to vol. ii, chart 3, fig. 18; chart 4, figs. 14, 18.

I. C. White: Catalogue of West Virginia University, pp. 60, 61, 63, 64.

C. N. Brown: Vol. vi, p. 619.

Uniontown, which is apparently at the place of Waynesburg A, the same with that in Brookfield at 55 feet above the Waynesburg coal bed and 2 feet 6 inches thick.*

Monroe county, east from Noble, is south from Belmont along the Ohio river. Only the lowest part of the Dunkard remains in the western townships, but the section lengthens eastwardly and on the Ohio river line one finds the highest rocks in the state. In Center township Professor Andrews measured

	Feet	Inches
1. Red beds, with a thin limestone	63	0
2. Concealed	31	0
3. Massive sandstone	20	0
4. Coal bed	0	6
5. Concealed	23	0
6. Coal bed [Washington]	1	6
7. Shales	70	0
8. Coal bed [Waynesburg A]	Blossom	
9. Interval with trace of [Waynesburg] coal bed	100	0
10. Coal bed and partings [Uniontown]	5	9
11. Interval	75	0

to the Cement limestone above the Upper Sewickley coal bed. This succession is characteristic of the valley of Sunfish creek; thence to the Ohio river, where, at Clarington, Doctor White's section shows the three coal beds 65 and 98 feet apart and the Waynesburg A is 3 feet, so that the Washington is 166 feet above the Uniontown (Clarington) coal bed. Massive sandstone rests on the Waynesburg A and 5 beds of red shale are within 190 feet above the Washington. All are rather thin and the total is 50 feet. Limestone seems to be absent from Doctor White's section, which extends above the place of the Upper Washington. The Jollytown coal, if present, is concealed. The relations here are very nearly the same as at Bellair, where the Washington is 64 feet above the Waynesburg A. Professor Andrews traced the Washington and Waynesburg A into the northwest corner of Salem township, where the beds, 70 feet apart, are 2 feet and 3 feet 8 inches thick. The lower bed is double.

Coal, 2 feet 8 inches; clay, 0 feet 2 inches; coal, 0 feet 8 inches.

At half a mile north, in Switzerland township, the Washington coal bed is 4 feet thick and a crumbling limestone, the Nineveh, 6 feet 2 inches thick, is 368 feet above it by barometer, the dip being neglected. A red bed, 18 feet thick, and a massive sandstone, 48 feet, are at 23 and

* E. B. Andrews: Vol. i, pp. 311, 312, 342.
C. N. Brown: Vol. v, pp. 1066, 1069, 1075, 1077.

70 feet below the limestone, but the rest of the interval is concealed. A limestone seen elsewhere was supposed to be about 150 feet below the Nineveh. The longest section in the state is that measured by Professor Andrews at Baresville, in Ohio township. Somewhat condensed, it is:

	Feet
1. Coal bed [Baresville]	Blossom
2. Concealed	145
3. Limestone [Nineveh]	6
4. Shale	18
5. Sandy limestone	2
6. Red shale	14
7. Shale	41
8. Sandstone	36
9. Mostly shales, two red beds	84
10. Coal bed [Jollytown]	Blossom
11. Shales, sandstones, quite well exposed	149
12. Coal bed [Washington]	1
13. Clay, shale, sandstone	20
14. Concealed	156
15. Sandstone shale	18
16. Coal bed [Uniontown]	2

ending at 45 feet above the Ohio river. The highest coal bed is taken to be equivalent to that seen in southwestern Pennsylvania. This correlation is especially probable, because, unlike the lower intervals of the Dunkard, that from the Nineveh limestone to the Gilmore sandstone is strangely uniform in the area of western Greene and the immediately adjacent part of West Virginia. The succession below the Nineveh limestone is the same as at Switzerland. The same limestone is seen on the opposite side of the river, where Doctor White made the interval 382 feet to the Washington coal bed; the difference is due, no doubt, in part to neglect of dip and in part barometric variations, for the measurement is not direct in either case. Doctor White long ago correlated this limestone with the Nineveh, and his suggestion has been confirmed by the observations in northern West Virginia, which show one constant limestone horizon between the place of the Upper Washington and the Gilmore sandstone. The exposure appears to be practically complete at Baresville between the Jollytown and Washington coal beds, but there is no red shale present, which accords with the New Martinsville section on the opposite side of the river, where the red beds are so insignificant that they might be overlooked. The interval between the Washington and Uniontown coal beds is 24 feet more than in Center township. The Waynesburg A is concealed here as well as at Sardis, in the southern

part of the township, where the Washington, 190 feet above the Uniontown, is double and 2 feet 3 inches, including a clay parting of 3 inches. In the extreme southern part of the county, on the river and about 2 miles west from Sistersville, in West Virginia, the interval is still 190 feet and only a trace of the Waynesburg A remains. A massive sandstone overlies Waynesburg A and underlies 35 feet of red shale.*

On the western border of Washington county, south from Monroe, the Waynesburg sandstone, 240 feet above the Pittsburg coal bed and 30 to 50 feet thick, is 40 to 60 feet above the Uniontown (Hobson) coal bed. In Decatur township this sandstone overlies a trace of the Waynesburg coal, and in Fairchild there is an impure limestone at 10 feet above it. Along the northern border of the county Professor Andrews's sections extend to only a few feet above the Uniontown coal, except in one case, where a limestone in red shale is noted at 91 feet above the Waynesburg coal, which is 147 feet above the Upper Sewickley. This is the red sometimes found under the Washington coal. In Liberty township, about 14 miles west from the Ohio river, Mr Minshall measured

	Feet	Inches
1. Shales and sandstones	100	0
2. Coal bed [Jollytown]	1	8
3. Shales, sandstones	140	0
4. Coal bed [Washington]	2	6
5. Shales, limestone, sandstone	59	0
6. Coal bed [Waynesburg A]	1	3
7. Limestone, shales	66	0
8. Pebbly sandstone [Uniontown]	28	0
9. Shales	6	0
10. Coal bed [Uniontown]		

The interval, Uniontown to Washington, is 160 feet, 10 feet less than in Center of Monroe, 16 miles north, and 30 feet less than at Baresville, while that between Washington and Jollytown is only 9 feet less than at Baresville, 14 miles northeast. On the Ohio river about 2 miles south from the Monroe county line and almost due east from Mr Minshall's section, Professor Andrews found

	Feet
1. Coal and shale [Jollytown]	5
2. Concealed	150
3. Coal bed [Washington]	Blossom
4. Concealed	18
5. Limestone	Not measured
6. Concealed to Ohio river	68

* E. B. Andrews: Vol. ii, pp, 578, 585, 586, 587, map 13, figs. 6, 10, 11, 23. I. C. White: Catalogue, pp. 63, 64, 69.

Doctor White has a section near Grandview, 4 miles farther down the river, in which the Washington coal bed is 150 feet above low water, the rocks rising in this direction, and at 3 miles farther down he finds on the West Virginia side the Washington at 150 to 160 feet above the Uniontown. In the Grandview section, obtained on a steep hill overlooking the river, the measurement reaches to 370 feet above the Washington, but does not reach the Nineveh limestone; so that the measurement at New Martinsville is to be accepted rather than those by Professor Andrews. A mark of coal is at 250 feet above the Washington, but the Jollytown, if present, is concealed. There is no sandstone in the Waynesburg interval and the Washington coal bed rests on 10 feet of red shale. The sandstones of the section are mostly fine grained and laminated and the massive grindstone beds of the Marietta region seem to be unrepresented. As stated on a preceding page, the red beds are numerous, beginning at 15 feet above the Washington coal bed; there are 5 beds in 330 feet, in all 65 feet thick. The Cowrun anticline, or "Oil-break," is crossed by the Ohio river at a few miles below Grandview, and Dunkard rocks are reached again only as one approaches Marietta.

At about 3 miles west from the Grandview section the Waynesburg is represented by a laminated sandstone 40 feet above the Uniontown (Hobson) coal bed, and a massive rock, rather coarse and 30 feet thick, is at 102 feet above that bed. A coal bed is reported in Muskingum township at 114 feet above what is taken to be the Uniontown (Hobson) coal bed; this is west from the anticline. The higher bed underlies 36 feet of reds, and another red bed, resting on 2 feet of limestone, is 56 feet higher. The Uniontown seems to be recognizable in Barlow, on the Meigs County border, where a thick red is at 140 feet above it. The Washington coal bed is present in Marietta township and the associated rocks are shown along the river just below Marietta, in Warren township, where Professor Andrews found the coal bed at 46 feet above the river with the grindstone beds above it. Farther down is Doctor White's section:

	Feet
1. Sandstone, quarried for grindstones	45
2. Concealed, some red marly shale	30
3. Gray sandy shale	10
4. Sandstone, quarried for grindstones	45
5. Shale	3
6. Coal bed [Washington]	1
7. Concealed	60
8. Coarse massive sandstone to low water	15

The grindstone beds, the Marietta sandstones of I. C. White, are thicker than where they are shown just below Marietta; they are absent from the few recorded sections west from the Ohio. The lowest member of Doctor White's section may be taken as the Waynesburg sandstone, which farther down the river becomes so prominent. As the course of the river changes, the rocks fall, and at 7 miles down below Marietta the Washington coal bed is but 20 feet above low water. A higher coal bed is reported here by Professor Andrews, but the interval is not given. The Washington coal is in the river bed at Belpre, opposite Parkersburg, but the river changes its direction there and within 4 miles the coal is 90 feet above low water and 25 feet above a massive pebbly rock, exposed for 20 feet. This at times is continuous below with the Waynesburg sandstone, giving a thickness of 100 feet and practically filling the interval from the Washington to the place of the Waynesburg coal bed.*

The Waynesburg sandstone, 250 feet above the Pittsburg coal bed and occasionally resting on a thin representative of the Waynesburg coal bed, is present in eastern Athens county. Professor Brown found a coal blossom at 135 feet above the Uniontown, or 330 feet above the Pittsburg. The Dunkard should be present within a considerable area in eastern Meigs, south from Athens and Washington, but there is little available information respecting it. Professor Lovejoy has traced the Waynesburg sandstone into the county, finding it coarse and 30 to 50 feet thick, with occasionally the Waynesburg blossom under it. In two townships he finds a coal blossom at 110 feet above the Waynesburg blossom. Professor Andrews notes a coal bed, approximately 336 feet above the Pittsburg, in Sutton township, and in Chester, about 3 miles north from the river, he measured

	Feet
1. Shale	50
2. Sandstone and shale	11
3. Coal bed [Washington]	2
4. Clay and shale	5
5. Sandstone and conglomerate	49
6. Shales	46
7. Sandstone and shale	35

At Lebanon the coal bed is 3 feet thick and 160 feet above the Ohio river. The conglomerate sandstone, rising or falling according to the course of the river, was followed by Doctor White from the Washington line to about 16 miles east from Pomeroy, where it passes under the river

* E. B. Andrews: Vol. ii, pp. 461, 462, 463, 465, 466, 467, 472, 477, 505.
I. C. White: Catalogue, pp. 73, 74, 80, 82, 83.
F. W. Minshall cited by I. C. White: Bulletin no. 65, p. 29.

bed with the Washington coal bed at 40 feet above it. It comes up again at Letart Falls, and at Antiquity it is exposed to the thickness of 40 feet, its bottom being 240 feet above the Pittsburg coal bed as measured in a shaft.*

WEST VIRGINIA

Returning now to the eastern border in West Virginia.

The surface observations thus far available are comparatively few, as the studies have been confined almost wholly to economic matters. Doctor White has recorded incidental observations along the middle of the great trough, showing clearly that he has traced the more important higher horizons from the Pennsylvania line southwestwardly through western Monongalia, Marion, and Harrison, eastern Wetzel, Tyler, and Doddridge counties, where the Gilmore sandstone caps most of the highest hills, on some of which there still remain the Windy Gap limestone and a higher sandstone, which is exposed at only one place in Pennsylvania. The Jackson limestone, 100 to 120 feet below the Windy Gap limestone, extends into Wetzel county. The Nineveh coal bed has been recognized in Monongalia and Wetzel counties, where it is from 6 to 25 inches thick and yields excellent coal. The Nineveh limestone is persistent, appearing wherever its place is exposed as far south as Jackson county and possibly almost to the Great Kanawha river. The Dunkard coal bed and another, either the Boyd or Jollytown, are present to a considerable distance from the Pennsylvania line. The Upper Washington limestone disappears quickly, the Lower seems to be present almost to the line of the Baltimore and Ohio railroad in Harrison county, but the Middle Washington and Blacksville appear to be practically wanting throughout. Notes respecting lower formations are given in some of the well records.

The Washington coal bed is present in Monongalia and Marion counties on the northeast side of the area, retaining its characteristic features throughout. Near Farmington, in the latter county, it is 10 feet 9 inches thick, with 14 layers of coal and shale. A single record in Marion county gives the interval to the Waynesburg as 143 feet, with the Waynesburg A at 45 feet above the lower bed. The Waynesburg sandstone, 35 to 62 feet thick, is a well marked horizon in all of the records and it frequently cuts out the Cassville shale. No record gives details above the Washington coal bed and those giving details below that coal

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* E. B. Andrews: Vol i, pp. 258, 259, 268.
I. C. White: Catalogue, p. 83.
C. N. Brown: Vol. v, p. 1062.
E. M. Lovejoy: Vol. vi, p. 627, 628.

show no red beds. The Wetzel county records, though very numerous, give little information respecting the Dunkard. The Nineveh limestone in the northeast corner of the county is 615 feet above the Waynesburg, which is 340 feet above the Pittsburg. The Waynesburg coal bed becomes an uncertain horizon in this county, but it is often recorded on the east side, where it is 340 to 350 feet above the Pittsburg, and the Washington varies little from 515, or 170 feet above the Waynesburg. Midway in the county the Washington is usually about 475 feet above the Pittsburg, and exposures above a boring at Pine Grove show it 221 feet above the Uniontown coal bed of that record. The Washington is exposed at many places between Pine Grove and New Martinsville, on the Ohio river, and it is mined for domestic use, though it yields only a small proportion of good coal. On the northern border of the county, at 10 miles east from the Ohio river, the Washington is 109 feet above the thin Waynesburg and 446 feet above the Pittsburg, but near the river, just over the line in Marshall county, the Waynesburg is only 306 feet, so that the Washington would be not more than 410 feet above the Pittsburg, or about 175 feet above the Uniontown. The Washington is exposed at several places along the river and is mined at New Martinsville, where it is 382 feet below the Nineveh limestone. Red beds, though numerous, are comparatively unimportant in Wetzel county, and are rarely more than 5 feet thick.*

The Washington coal bed seems to be persistent in western Harrison county, and it has been mined at places along the Baltimore and Ohio railroad. In the northwestern part of the county it rests on a thick sandstone, and red beds 5 and 90 feet thick are at 6 and 50 feet above the coal. The Waynesburg A rests on 11 feet of reds, and a bed 20 feet thick overlies the place of the Waynesburg coal. At Sedalia, in Doddridge county, a diamond-drill core shows neither coal nor red shale in 189 feet above the Uniontown coal bed, but at 3 or 4 miles west the Washington coal is 190 feet above the Uniontown, and two red beds, 50 and 12 feet, are at 20 and 123 feet below it, both in the Dunkard. Another bed, 10 feet thick and 100 feet above the Uniontown, is in a well on the western side of the county where the others are wanting. A well near the Tyler line shows the Washington 504 feet above the Pittsburg, 64 feet less than in northwest Harrison county. That coal bed is present in Doddridge southward to beyond the Baltimore and Ohio railroad and it is mined in a small way at many places. It is double or triple and always yields poor coal.

* I. C. White: Catalogue, pp. 67, 69. West Virginia Geology, vol. i, pp. 238, 241; vol. ia, pp. 127, 128, 178, 202, 212, 213; vol. ii, pp. 106, 107, 109, 110, 112, 114, 137.

Near the eastern border of Tyler county, northwest from Doddridge, the Washington seems to be about 465 feet above the Pittsburg and the Waynesburg A is about 65 feet lower. A detailed section at Wick shows the Washington 191 feet above the Uniontown, with red beds, 46, 23, and 50 feet thick at 35, 225, and 260 feet above it, and another of 15 feet at 95 feet below it. The interval to this lower red is filled almost wholly with sandstone. Massive sandstones 15, 38, 20, and 60 feet thick are at 20, 115, 135, and 165 feet above the Washington, the first three certainly falling within the Marietta interval. Here the Washington is 444 feet above the Pittsburg. At a few miles northwest in Ohio, opposite Sistersville, this interval has decreased to 407 feet. Doctor White's section on the Ohio river 9 miles below New Martinsville shows red beds 10, 10, 15, 5, 10, 5, and 35 feet thick at 70, 92, 117, 232, 333, and 348 feet above the Washington coal bed, the last being that under the Nineveh limestone. Only the fourth bed is recorded at Wick. The Marietta sandstones are insignificant. At Middlebourne, midway in the county, the well records show the Washington at 185 to 190 feet above the Uniontown, as at Sardis, Ohio, 10 miles north.

In Pleasants county, west from Tyler, one approaches the "Oil break," and the rocks rise rapidly toward the west, so that the oil borings seldom begin in Dunkard rocks. The only available information is Doctor White' s section on the Ohio river at Raven rocks, about 3 miles below the Tyler line, where are two massive sandstones 20 and 45 feet thick at 63 and 123 feet above the Washington coal bed and therefore in the Marietta interval; there are at least 30 feet of red rock in 48 feet above the coal bed. These sandstones, evidently the Upper and Middle Proctor of Doctor White's earlier studies, have been seen frequently along the river and they are reported as present at many places in the interior from Marshall county southward. A variable sandstone makes its appearance below the Washington coal bed which becomes coarse beyond Parkersburg, where the Waynesburg sandstone, wholly unimportant in much of Wetzel, Harrison, Doddridge, Tyler, and Pleasants, becomes an important member of the section. The interval, Washington to Uniontown, is about 160 feet at Raven rock, 20 feet less than at the last recorded measurement in Tyler and very nearly the same as in northern Washington of Ohio.*

In Ritchie county, south from Tyler and Pleasants and west from Doddridge, there is nothing above the Washington coal bed except a dismal succession of shales and sandstones, all variable to the last degree.

* I. C. White: Catalogue, pp. 71-74. Geology of West Virginia, vol. i, pp. 328, 329, 332; vol. ia, pp. 249, 250, 258.

The Marietta interval is as variable as the rest, but at most localities it contains sandstone and occasionally that rock predominates. A great sandstone is usually present at 40 to 50 feet below the Washington coal, and it is sometimes continuous with the Uniontown sandstone below. The Washington coal seems to be persistent throughout the county, being reported at many places by both White and Stevenson; it is 1 foot to 2 feet 9 inches thick and usually double. Records giving details above the Washington are few, but they show that the red beds are as variable as the rest; for in three wells, reds, 26, 35, and 50 feet are at 44, 100, and 130 feet above the coal; but each is in only one well, its place in the others being filled with sandstone.*

Wood county, west from Ritchie and Pleasants, adjoins Washington of Ohio. The Washington coal bed, thin and slaty, is in the Ohio river at Parkersburg with one of the Marietta sandstones at 90 feet above it. The persistent Nineveh limestone is in the hills, 3 or 4 miles east from the river, where a well record shows a great sandstone, 119 feet thick, at 236 feet below the limestone and 10 feet above a coal bed. This direct measurement gives as interval between the limestone and the coal bed, 365 feet, placing the coal at the Washington horizon and the sandstone in the Marietta interval. A great mass of red shale underlies the Nineveh limestone; a bed 16 feet thick rests on the Marietta sandstone and a thin bed is at 5 feet above the Washington. This coal bed rests on 55 feet of red, with at 55 feet lower a great sandstone belonging mostly to the Uniontown; but the section is excessively variable. At 3 miles northeast the Marietta sandstone is wanting, and for 200 feet above the coal one finds an alternation of red and other shales, with the beds differing even in adjacent wells; thus one well shows two beds of red, 100 and 40 feet, while another only a few rods away has 60 and 20 feet in the same interval. But it is sufficiently evident that red shales are in greatly increased thickness, both above and below the Washington coal bed. The Nineveh limestone is exposed in eastern Wood, at the corner of Wood, Jackson, and Wirt counties, as a mass of limestone and calcareous shale 30 feet thick.†

There is practically no detailed information for counties south from those already followed. Dunkard is certainly present in Jackson, Wirt, Roane, Calhoun, and Gilmer, and no doubt it crosses the Great Kanawha river. Doctor White has recognized the Marietta sandstones in the counties named, and the Washington coal bed has been opened at many

* Geology of West Virginia, vol. i, pp. 311, 313, 317; vol. ia, pp. 406, 416, 431, 434, 435; vol. ii, p. 114.

† Geology of West Virginia, vol. i, pp. 291, 294, 295, 296; vol. ii, p. 109.

places in Roane county; for, though only 12 to 24 inches thick it is the only coal bed in the region. It is hardly probable that the succession will ever be worked out. The limestones and coal beds, with the exception of the Washington, have all disappeared, the sandstones are indefinite, and the red beds are inconstant to the last degree. To follow the section with any degree of certainty seems almost impossible. In this part of the field there are no natural division planes above the Allegheny.

Geographical Changes during the Pennsylvanian*

Toward the close of the Devonian, the Appalachian water area had decreased to a basin at the east, 70 to 80 miles wide at most, extending from the Catskill mountains of New York across Pennsylvania, Maryland, and Virginia to a short distance beyond New river, in the last state. The Catskill beds, deposited in this narrow basin, which in southern Pennsylvania reached westwardly only to Laurel hill, about 60 miles east from the western boundary of the state, are red to green shales and sandstones, fine grained and argillaceous, many of them little more than indurated clay beds.†

The close of the Devonian was marked by elevation at the east and slow subsidence toward the west and south—a reversal of the conditions prevailing during the later Devonian. The earlier Mississippian deposits, comparatively coarse on the easterly side to beyond New river, in Virginia, eventually reached far into Ohio. The subsidence toward the west was not of long continuance in the northern part of the basin and was followed by elevation on that side, so that the western limit of each Mississippi formation in Ohio and northern Kentucky is east from that of its predecessor; but the subsidence continued toward the south for a much longer period, and the later Mississippian overlaps even the earlier Devonian, while its limestones pass into sandstone in approaching the old land area of eastern and southern Alabama, though even there some elevation occurred before this time closed. The narrowing of the basin brought about conditions at the close of the Mississippian resembling those at the close of the Devonian.

* As the writer is preparing another work, in which the facts thus far gathered will be discussed in their bearing upon the origin of coal and the accumulation of coal beds, it is necessary here only to summarize the varying relations of land and water during Pennsylvanian time.

† The term Catskill is used here as by Vanuxem, who first defined and named the "Catskill group." It has no reference to color of the beds, which is due to a condition beginning in New York at the close of the Hamilton and thence gradually extending southward until, at the close of the Devonian, it prevailed throughout the area of deposit.

That all but an insignificant part of the Appalachian basin had become dry land at the beginning of the Pennsylvanian was suspected long ago. In 1874 Professor Newberry * thought that some of the West Virginia coal beds were older than the Ohio conglomerate, and in the following year Professor Andrews † asserted respecting certain plants obtained at the bottom of the Ohio column that "their stratigraphical position is more than 2,000 feet above the base of the series as revealed in the geosynclinal basin of West Virginia, which was first filled with strata of the Coal Measures before any similar formations took place upon the ancient marginal Waverly plateau of Ohio." A year later Mr Maury,‡ making use of measurements by Professors W. B. Rogers and W. M. Fontaine, called attention to the great difference in extent of the deposits in the northern and southern parts of the basin; but the erroneous conceptions concerning correlation then prevailing prevented him from recognizing the full value of his data. Fifteen years afterward Doctor White § compared the Ohio and Pennsylvania Pottsville with that of West Virginia and indicated the vast thickness in West Virginia of rocks below the Jackson Shaft coal horizon of Ohio, illustrating his understanding of the relations by a diagram. In the interim Mr Lesquereux ‖ had tabulated the distribution of plants obtained from Pennsylvania and had shown the existence of horizons in Tennessee below those of Ohio, and had compared the lower horizons with those in the anthracite region of Pennsylvania. It was reserved for Mr David White, after study of fossil plants collected systematically in many portions of the basin, to present the conclusion in definite form and to determine the relation of the earlier anthracite deposits to deposits in other parts of the great area.¶ His studies, based primarily upon paleontology, led to practically the same conclusions with those reached by the writer from study of stratigraphy and presented in the following pages. The two lines of investigation have not led in all cases to full agreement in correlation, but it must be conceded that the disagreements are confined mostly to localities where the stratigraphical evidence is incomplete.

At the beginning of the Pennsylvanian the water area was confined to lakes on the eastern side of the basin, one in northeastern Pennsyl-

* J. S. Newberry: Geology of Ohio, vol. ii, 1875, p. 167.

† E. B. Andrews: Palæontology of Ohio, vol. ii, 1875, p. 415.

‡ M. F. Maury, Jr.: Resources of West Virginia, 1876, p. 187.

§ I. C. White: U. S. Geol. Survey Bulletin, no. 65, 1891, p. 182.

‖ L. Lesquereux: Coal flora of the Carboniferous formation of Pennsylvania and throughout the United States, 1880, pp. 636 et seq.

¶ D. White: Deposition of the Appalachian Pottsville. Bull. Geol. Soc. Am., vol. 15, 1905, pp. 267 to 282, and map.

vania, another in West Virginia and Virginia, and possibly a third in eastern Alabama, though evidence for the last is very indefinite. The lakes were bordered by flats covered with Shenango muds, while farther away on each side were rocks of greater age. That the land on the west side had been exposed for a long period to subaerial erosion is evident from the existence of deep valleys, clearly shown for Kentucky and Ohio in sections by Andrews, Read, Crandall, Sullivan, and Campbell; for Tennessee and Pennsylvania by Hayes, D. White, W. G. Platt, and other observers. The highland of the basin was in New York and western Pennsylvania. From the latter the surface declined gently westward into the broad valley of eastern Ohio and eastward to the deep valley now occupied by the Southern Anthracite field. Toward the south the decline was long and gradual, with more rapid descent on the east than on the west side. The great depth of the northern valley basin and the steepness of its immediately bounding slope at the west are evident, because, even at the close of the Rockcastle, deposits reached barely into the Northern Anthracite field. The land was trenched by great valleys, hundreds of miles long, ending in bays, some of which opened into the Atlantic, others into the interior sea.

The northern lake basin containing the Pocahontas, or lowest beds of the Rockcastle, included the Southern and much of the Western Middle anthracite fields. This, first made evident by Mr David White's studies, is equally evident from the stratigraphical conditions. The southern lake basin may have been somewhat larger than indicated by Mr White, who, out of abundant caution, did not place the boundary beyond that indicated by undoubted evidence in his possession. The stratigraphical evidence seems to justify farther extension southward to very near the Tennessee line, at least for the higher beds. The basin thus extended would be about 100 miles long, with an extreme width in southern West Virginia of not more than 60 miles. These small basins, now separated by an interval of 300 miles, may have been united; but if they were, the connecting water strip must have been very narrow, for even in southern Pennsylvania the Sharon sandstone, the latest Rockcastle deposit, is the oldest bed in Broad Top of Fulton county.

The eastern shoreline of the northern basin lay not far from the south side of the Southern Anthracite field and nearer to the eastern than to the western end. Mr David White * has shown that pebbles in the lower third of the Pottsville there are less rounded than those in the upper Pottsville, at times even subangular, while along with the prediminating quartz fragments there are in this lower portion

* D. White: 20th Ann. Rept. U. S. Geol. Survey, 1900, p. 764.

others of shale and sandstone. He states also that fragments increase in size eastwardly, there being at the east end many 5 to 6 inches in diameter. These large pieces, as well as those of shale and sandstone, could not have been transported far. Mr Lyman* calls attention to the rapidity with which the fragments decrease in size northwardly as evidence of speedy loss in transporting power. Comparisons of tabulated sections given in the Anthracite atlases of the Pennsylvania survey shows that conglomerate areas are separated by areas of finer deposits in which shale is abundant. The conditions are such as would be found in a lake basin filled with confluent delta deposits.

The eastern border of the West Virginia-Virginia basin is not so apparent. At both the north and the south end the lower beds of the Pocahontas are more or less conglomerate, but midway along the outcrop no conglomerate is seen and even such sandstones as are present are not coarse. But in this basin the deposits quickly lose their coarseness toward the west, and the Pocahontas coal bed itself diminishes in that direction, so that there is much probability in Mr M. R. Campbell's † suggestion that the present outcrop line is not far from the original eastern limit of the basin.

Elevation at the east and depression on the west side of the great basin became more pronounced after the Pocahontas deposits had been laid down. Great sandstones were spread over the region, all extending farther northward on the east than on the west side, while each in turn overlaps its predecessor and for some distance before disappearance rests on Mississippian beds. The Rockcastle sandstone was the first to reach the deep valleys of Kentucky and Ohio, and in the latter state it seems to occupy a broad valley along the western margin of the Carboniferous field, extending from Lake Erie southwardly into Kentucky, where it may be that the valleys described by Campbell and Sullivan were its tributaries. In the northern and northwestern parts of the great basin the subsidence was nearly uniform, there being but slight variations in the section; but from Kentucky southward there was clearly a constant increase along the easterly side into Alabama, where throughout the subsidence was very great, the Rockcastle deposits being several times as thick in Alabama as along the western escarpment of the Tennessee plateau. Yet this subsidence was not without irregularities and local foldings, for intervals between the great sandstones show at times remarkable variation. There were long periods of comparative quiet,

* B. S. Lyman: Original southern limit of the Pennsylvania anthracite beds. Trans. Am. Inst. Min. Eng., 1902.

† Cited by D. White in Bull. Geol. Soc. Am., vol 15, p. 276.

during which coal beds of great extent and great economic importance were formed.

The ocean found ingress at few localities and apparently for only brief periods. Professor Safford * discovered a limestone in Grundy county of Tennessee within the Bonair and very near the extreme western outcrop. This, as he states, a rare occurrence in Tennessee, contains a marine fauna, evidently marking the head of a bay communicating with the interior sea. Mr M. R. Campbell reports a fossiliferous shale not far above the Etna horizon in McDowell county of West Virginia, 300 miles northeast from Professor Safford's locality and only about 15 miles from the extreme eastern outcrop; and Mr David White has observed marine forms very near the same horizon on New river, east from Sewell. This may mark the head of a bay opening to the Atlantic. No marine fossils have been observed anywhere in the intervening space. In central Alabama, Mr McCalley found several beds with marine fauna in the higher part of the column, but no observer has recorded the presence of marine forms in either Georgia or eastern Alabama.

The post-Pocahontas sandstones of the Rockcastle give a clue to the land boundaries. In ascending order they are the Etna, Bonair, Rockcastle, and Sharon. All are conglomerate to coarse, more or less pebbly sandstones at most localities along the easterly border. Followed westwardly in Alabama, the Etna becomes a not very coarse sandstone and the Bonair shows only occasional pebbles; but beyond the central part of the state both beds thicken toward the western border, indicating that the land area, so distinct on the east and south, must have extended northwardly on the west side through Mississippi almost to the Tennessee line. There, however, one is beyond the strict limits of the Appalachian basin and is in line with the Indiana-Illinois area, cut off abruptly by erosion in Kentucky 200 miles north from the Alabama exposures. At the extreme western outlier in Tennessee these two sandstones are cross-bedded and not coarse, and the Etna retains these characteristics at most localities in central and western portions of the Tennessee coal field; but the Bonair is usually more or less conglomerate and is very coarse near its termination, in the northern portion of the state.

The Rockcastle and Sharon sandstones cannot be recognized in central Alabama; there is good reason to suppose that the higher bed is no longer present, having been removed by erosion. But sandstones and conglomerates are so numerous and so considerable in the upper part of the column as to leave no room for doubt respecting continuing elevation of the inclosing area east, west, and south. In much of the central and western part of

* J. M. Safford: Geology of Tennessee, p. 367.

the Tennessee coal field the Rockcastle is a more or less pebbly sandstone, but on the west side, at the north, it becomes distinctly conglomerate and it retains this character in Kentucky. It is notably conglomerate, especially in its lower portion, everywhere in Ohio, and in the northern 150 miles of its extent it carries abundant fragments of chert or cherty limestone containing Mississippian fossils; while near Lake Erie it holds not only quartz and chert pebbles, but also very numerous flat and angular fragments of rock. This distribution in Ohio clearly indicates a broad gravel-filled valley like that of the upper Ohio. The nature of the fragments shows that they were derived for the most part from the vicinity of the present Lake Erie. The chert at one time was supposed to come from the Maxville limestone of southern Ohio, but the deposit is far to the north and west of the original limit of that limestone, which is not reported anywhere as cherty; the source must be looked for in the cherty Mississippian limestone of Michigan. The valley holding the Rockcastle lay for the most part west from the present area of Pennsylvanian deposits, being well marked only near Lake Erie and in Pike and Jackson counties of Ohio. In the intervening space one finds only the eastern edge of the valley and in many places apparently the insignificant deposits laid down in lateral valleys. In Kentucky and Tennessee the distribution of this sandstone is not confined to narrow areas. The Sharon sandstone tells the same story as the Rockcastle, but has a wider distribution. It, like the Rockcastle, is coarser at the sides than in the middle of the great basin, so that the material forming it was derived not from one but from both sides.

At the close of the Rockcastle, water extended to but a little distance within New York. Practically the whole of the Pennsylvania bituminous area, the Northern Anthracite field, the northwestern third of West Virginia, and nearly all of the present coal area of Ohio were dry land. A shallow, rather narrow arm of the interior, or Mississippian, sea extended northward from Kentucky to the east side of what is now Lake Erie, occupying the old valley partly filled with Rockcastle deposits, while other valleys communicated with the Atlantic at the east. The elevation of the land must have been insignificant throughout, for at the close of the Beaver the whole region had received deposits.

The passage from Rockcastle to Beaver is somewhat abrupt at many places along the western and northern sides of the great basin. The surface of the Sharon sandstone is irregular, so that in western Pennsylvania and in Ohio the Sharon coal bed occurs in saucer-like patches, while in Kentucky the interval from Sharon sandstone to Sharon coal varies abruptly from 10 to 50 feet or even more. These variations may

be due to irregularity in distribution of sediments or even to local elevation or subsidence, but in many cases they are such as to suggest genuine lack of conformability due to a broad elevation along the western side, which, in addition, would explain the abrupt change from coarse sandstone to fine shale, if it be supposed sufficient to divert the drainage temporarily and to make the low interior land the important source of sediments. Subsidence during the Beaver seems to have been comparatively uniform in the northern part of the basin, though there is evidence of somewhat more subsidence in the east than in the west; but in Kentucky and southern West Virginia the rate of subsidence increased southwardly and eastwardly with notable rapidity. The shales below the Sharon coal bed are but 10 feet thick at the western outcrop in Kentucky. Mr J. Lesley followed them across the state to the West Virginia border, where they are 150 feet, while on the Kanawha river, in West Virginia, they are 400 feet thick. This differential sinking continued throughout the Beaver, for intervals above the Sharon coal bed show notable variations in the southern part of the remaining area.

In southern Pennsylvania and the immediately adjacent part of West Virginia the sedimentation was continuously marine from the Shenango up to the middle of the Beaver, there being no recognizable members of the Beaver or older beds below the Quakertown coal bed, and the passage beds are largely red shale, with locally important deposits of iron ore. These contain in some places marine forms, thoroughly well developed and of large size, as if living amid favorable conditions. This continuous sedimentation prevailed in a broad area and leads to uncertainty in the attempt to interpret oil-well records within the interior counties of West Virginia, where a sandstone sometimes divides them. In northern Kentucky Professor Crandall found in shales below the Sharon coal bed numerous calcareous concretions, apparently non-fossiliferous. These increase in number as well as size farther south, at the same time ascending in the series until in the southern part of the state they reach to what has been taken by the writer to be the Mercer horizon; but concretions above the Sharon coal become more and more arenaceous. Mr J. Lesley observed these concretions long ago and followed them from the western outcrop across the state to the West Virginia line, where they are the silicious limestones of Doctor White's Winfield section. This deposit is reported from Logan county of West Virginia, but thence eastward, possibly because of imperfect exposures, at no place until the Kanawha river is reached. There one finds the concretionary Campbells Creek limestone above, with the Stockton cement and the Eagle limestone below the Sharon (Campbells Creek) coal bed. No fossils are reported from

any locality west from the Kanawha, but Doctor White discovered an abundant marine fauna in shales associated with the Eagle limestone.

For the most part fresh-water conditions prevailed during the early part of the Beaver, and one may regard the marine forms found near the bottom of the formation on the east side as due to communication there with the Atlantic. At a much later time, however, subsidence on the westerly side admitted seawater to the broad valley on that side; so that in Ohio one finds extending southwestwardly from Mercer county of Pennsylvania to Perry county of Ohio the important Mercer limestones, extending farther eastward than does the Sharon sandstone, but apparently not so far west. As shown by Mr Read's * descriptions and as figured in one of his diagrams, the Ohio valleys were not filled by deposits until after the Mercer limestones had been formed. As the deep, broad valley in which the Rockcastle beds and the Mercer limestones were deposited was for the most part west from the present area of Coal Measures, the limestones can not be traced beyond Perry county, where the Lower Mercer is very thick at its western outcrop. These limestones carry a typically marine fauna.

The sandstones of the Beaver are the Connoquenessing and the Homewood. These can not be recognized farther south than northern Tennessee. Along the eastern outcrop they are sandstones, with few pebbles northward to northern West Virginia, beyond which into the Northern Anthracite field they are pebbly and at times largely conglomerate. On the western side they are sandstone, often shale, until near the last exposures at the north, where they sometimes contain pebbles. The one exception on the west side is in Knox county of Ohio, where one is on the extreme western outcrop. In the deeply buried interior area more or less sandstone is present at one or other of the intervals in nearly every boring, though there is great variation and very many borings show little aside from shale; but in an irregular east and west strip crossing Clearfield, Jefferson, Clarion, and Mercer counties of Pennsylvania, at a considerable distance south from the northern outcrop, one finds the Homewood sandstone coarse and at times coarsely conglomerate. The Homewood is pebbly also along a line extending from southern Fayette of Pennsylvania to the eastern outcrop in Maryland, as though a valley had existed there. The strip farther north evidently marks a river valley, but the source of the pebbles is difficult to determine. The distribution of the sandstones shows that the elevation continued on the east side, strongly at the north, but less and less strongly toward the south, while the pebbly rocks of Knox as well as of Summit and Portage, on the

* M. C. Read: Geology of Ohio, vol. iii, p. 544.

northern border in Ohio, may be evidence of slight elevation on that side, and the pebbles may have been derived from upraised Rockcastle beds.

The existence of land at the south and southwest is indicated by the distribution of the coal beds. These appear to be persistent around the borders of the basin, even at the south and southwest, to the last localities where one may recognize the formation; but they are wanting in the interior area within Ohio and West Virginia, where in thousands of square miles no trace of them appears in the well records.

At the close of the Beaver, though the whole basin had received deposits, the water was very shallow and the surface of the latest sandstone or shale showed surprisingly little irregularity. The abruptness of change in many localities from Homewood sandstone to fine shale of the Allegheny is one of the most notable conditions. Not less remarkable is the regularity of the subsidence in a vast area. The interval from Homewood sandstone to the Brookville (Stockton) coal bed varies little from 10 feet in a space of more than 1,000 square miles within West Virginia, while in other tracts equally extensive that interval varies from 5 to 20 feet. Whatever may have been the cause, a long period of very gentle change succeeded the Beaver, during which coal at the Brookville horizon, with greatest thickness at the east, gradually spread over the greater part of the area in which Allegheny rocks remain. Its extent is unequaled by that of any deposit at a later horizon.

The Allegheny is a thin formation, but its variations in thickness are considerable. Along the easterly side one finds 160 feet in Broad Top of Pennsylvania, 350 to 260 in the Potomac area, decreasing toward the west; 175 in Taylor county of West Virginia, beyond which it decreases to 140 feet, a thickness which is retained for many miles. Increasing again, it becomes 200, and at the Kentucky border about 210 feet, which seems to be approximately the thickness assigned to its beds in southeastern Kentucky by Mr Hodge. In the First and Second basins of Pennsylvania the measurements vary from 235 to 275, but along the west side of Chestnut hill it is 230 in Indiana county of Pennsylvania, 206 at the West Virginia line and 195 feet at Clarksburg, about 40 miles south from that line. The greatest thickness is in Jefferson, Armstrong, and Butler counties of Pennsylvania, becoming 340 feet in the last, whence it decreases toward the west and is barely 200 feet at the Ohio line. In that state the variation is between 175 and 240 feet, the least thickness being on the western border, whence it thickens eastwardly toward the middle of the basin, where in the deep portion of Ohio and West Virginia it is about 250 feet. There seems to be no reason for supposing that the Allegheny becomes thicker southward in Kentucky,

and at present there is little ground for supposing that it ever reached much farther south than northern Tennessee.

The sandstones of the Allegheny contrast greatly with those of the Rockcastle, even with those of the Beaver. They are persistent only as narrow bands, and in any given area are apt to be replaced for considerable distances by sandy or even by clayey shale. Along the eastern outcrop from Kentucky northeastwardly into Randolph and Upshur counties of West Virginia the sandstones are very conspicuous, very coarse, and at times for miles almost continuous from bottom to top of the formation, composing in part Mr Campbell's Charleston sandstone. Farther north, in the Potomac area, the sandstones are differentiated, broken by beds of shale; yet even there the Butler and Clarion are massive, the former at times pebbly. The sandstones are irregular in Broad Top and the pebbles are few. Within western Pennsylvania the Butler and Freeport sandstones appear to be most nearly persistent and each of them occasionally shows some pebbles; but they vary greatly in thickness and each of them is often replaced by shale in tracts containing hundreds of square miles. Well records in the deep portion of Ohio and West Virginia usually show more or less of sandstone in one or more of the intervals, but many show so little aside from shale that the sandstone must be due merely to local sorting of material. Pebbles are reported only from Wirt county of West Virginia. The great sandstones of the eastern outcrop in West Virginia break within a few miles toward the northwest; thin shales appear, which soon increase in thickness, and the sandstones become unimportant. Along the western outcrop in Ohio, sandstone is most nearly persistent in the Butler and Freeport intervals. Ordinarily fine in grain, the latter shows pebbly streaks in Stark, Carroll, Harrison, Wayne, Tuscarawas, and Muskingum counties—that is, along the northwestern side; yet in all of these counties not a few sections show only shale. The Clarion (Hecla) sandstone becomes very conspicuous in southern Ohio and is equally so farther south and southwest in Kentucky. It is noteworthy that a conglomerate is present in parts of Kentucky near the horizon of the Vanport limestone, and that at one locality the ore associated with that limestone is so crowded with quartz pebbles as to be worthless.

The character and distribution of the sandstones show sufficiently a great advance of the shoreline or a considerable elevation of land at the southwest. The former condition seems the more probable, and the Allegheny deposits can have extended hardly so far in that direction as did those of the Beaver. The shoreline at the east-southeast must have been at only a short distance from the present outcrop, as the strip of

sandstone is very narrow. Coarse material could be pushed only a little way in the shallow water of that time. There is much to suggest a similar advance of the shore at the northwest, not only in the unexpected coarseness of the sandstone, but also in distribution of the limestones. The presence and great predominance of sandstone in Kentucky, on the southern and southwestern borders, is equally suggestive of land encroachment in that direction.

The Brookville coal bed, the lowest of the Allegheny, underlies in most of the area sandstone or shale, but in Ohio, from Mahoning county on the Pennsylvania border at the north to Hocking and Perry counties at the south, one finds the Putnam Hill limestone, which is sometimes in direct contact with the coal. Throughout this distance the western edge of the limestone lies west from the present outcrop, and south from Perry and Hocking the place of the limestone is west from the present coal area; but conditions in Knox county seem to show that the limestone strip was narrow and that it did not extend beyond the valley region in which the Rockcastle and Sharon sandstones occur. Like the Mercer limestones, it carries an abundant marine fauna and marks the line of a sea invasion from the west. One finds on the Kanawha river, in West Virginia, and at the same horizon, the Black Flint, sometimes accompanied by limestone, at times fossiliferous itself and often associated with fossiliferous shales. This deposit is confined to a narrow branching area, which may have been near the head of a bay communicating directly with the Atlantic. A limestone at this horizon in northern West Virginia is non-fossiliferous.

The Vanport (Ferriferous) limestone marks a still greater inroad of the interior, or Mississippian, sea, reaching in northwest Pennsylvania almost to the New York line. Its easterly and westerly boundaries are distinct in Pennsylvania. At the north and northwest, in Elk, Clarion, Jefferson, and Butler, it passes into chert and cherty sandstone, while on the southeast a prong extends into central Indiana. The deposit is wholly wanting east from the Monongahela and farther north in the First and Second basins of Pennsylvania as well as in West Virginia; but a marine limestone belonging very near this horizon is in Maryland, 150 miles southeast from the nearest locality in Pennsylvania where the bed can be recognized. On the Kanawha, in West Virginia, Professor W. B. Rogers* found a bed crowded with marine forms at 140 feet above the Black Flint, too high for the Vanport horizon, but of interest as proving access to the Atlantic at more than one time during the Allegheny. During the deposit of the Vanport the water was evidently very

* W. B. Rogers: Rept. Geol. Survey of Virginia for 1839, p. 135.

shallow near the Pennsylvania-Ohio line, for in a considerable area that limestone is represented only by occurrences of fossiliferous shale, more or less calcareous; but the limestone reappears in central Tuscarawas county, and thence southward it is recognized as limestone or as ore to Breathitt county of Kentucky. In central and southern Ohio as well as in Kentucky the main body of the limestone lay west from the outcrop, and in much of the present area the horizon is traceable only by means of the ore bed, which extends eastwardly for some distance beyond the last trace of the limestone. The Vanport is richly fossiliferous.

No later important inroad of the sea occurred. The fossiliferous shale overlying the Middle Kittanning is found only as far north as central Ohio, while the Lower and Upper Freeport limestones, though extending over a great part of the basin at the north, are either non-fossiliferous or contain only fresh-water forms; but south from the Ohio river in Kentucky the Upper Freeport limestone carries a characteristic Carboniferous fauna.

It is wholly probable that the Appalachian and the Indiana-Illinois fields were not united during the Allegheny, though they may have been during the Rockcastle, as they were during the Mississippian.

Observers in Pennsylvania note at many places that the Homewood, the last deposit of the Beaver, is continuous with a sandstone in the Allegheny reaching at times to the Lower Freeport coal bed, but for the most part to about the Vanport horizon. At a little distance on each side the Allegheny portion of the sandstone disappears and the proper section is found. Records of borings in West Virginia show the same condition, with in some portions of the deeper area a much greater vertical extent. Mr Read gives a section in Coschocton county of Ohio where a continuous sandstone, 280 feet thick, occupies a trough in Beaver and Allegheny beds. Borings in Greene of Pennsylvania and Marshall, Tyler, and Wetzel of West Virginia seem to show narrow areas in which sandstone is continuous from Homewood far up into the Allegheny and in some instances even into the Conemaugh. These may mark stream courses, constantly agraded. It has been suggested that they are evidence of local foldings and elevations in which valleys were made by subaerial erosion. This explanation applies to very few of the examples, since there is no nonconformity on either side. For example, in the Ohio instance the Brookville coal bed rests on the sandstone, while at a short distance away the same bed is shown with the Beaver beds below, each with its proper interval for the region.

Beyond all doubt, there were serious local irregularities, for intervals often vary with extraordinary abruptness; but one must be cautious in

generalizing here. The interval between Upper Freeport and Lower Kittanning coal beds varies little and apparently according to rule in very considerable areas, while in the same areas the intervals between intervening coal beds vary without any reference to the principal interval. The coal beds of the Allegheny above the Brookville in no case extend far into the interior of the basin and all are mere fringes around the border. The coals mentioned in oil-well records can rarely be referred to any definite horizon, and in most cases they represent carbonaceous material drifted upon mud lumps or sand banks.

Toward the close of the Allegheny a small area in west central West Virginia near the Ohio river received deposits of red mud, more or less calcareous, accompanied often by greenish muds; and, somewhat earlier, similar deposits were made in northeastern Kentucky. This is the beginning of a condition which in gradually enlarging or contracting area was to continue until the close of Carboniferous time, always predominating, however, within a small area in West Virginia and the adjoining part of Ohio.

In many respects the Conemaugh is but the continuation of the Allegheny; the variations in thickness are, geographically, very similar in both. Along the easterly side the Conemaugh is approximately 500 feet thick in Broad Top, at the northeast, while at Charleston, on the Kanawha, 250 miles southwest, the thickness has increased to 643 feet; but in the intervening space for nearly 200 miles it averages not far from 600 feet. Along the northern border, in Pennsylvania, it is about 600 feet, and slowly decreases southwardly to 560 feet at the West Virginia line, this being apparently about the average thickness in West Virginia east from the line passing through Ritchie county. Midway in the basin the sections show decrease southwestwardly, 600 in western Pennsylvania, 480 in Monroe, and 430 in Lawrence of Ohio, while along the western outcrop in Ohio the thickness varies from 325 to 350 feet. The least thickness reported, 275 feet, is on the extreme western outcrop, in Perry county of Ohio, while farther east in that county it becomes 329. This decrease westwardly across the basin is due to differential subsidence and not to overlapping, for the notable members of the section persist to the last. The rapid shortening of the section in Perry county of Ohio seems to show that the shortline lay not far toward the west.

Except in a very narrow strip along the southeasterly border in West Virginia, the Conemaugh sandstones are more irregular than are those of the Allegheny. One generally finds some sandstone of some sort in the sandstone intervals, but shales predominate in by far the greater part of the area. Certain sandstones appear with great regularity in oil-

well records of West Virginia, but comparisons show quickly that the drillers' identifications are too often made at haphazard. Away from the southeastern border, pebbles are extremely rare, except along a narrow rudely east and west strip across Indiana, Armstrong, Butler, Lawrence, and Beaver counties of Pennsylvania. This lies many miles south from the northern outcrop and south from the similar strip in the Beaver formation; its variations are such as one finds in the gravels of the upper Ohio river. Many similar valleys filled with standstone during the long subsidence are recognizable in various parts of the area, and occasionally one is found along an anticlinal crest which seems to have been made by subaerial erosion. The sandstones for the most part are indefinite within Ohio, but in Tuscarawas county the Lower Mahoning interval is filled with conglomerate and farther south the Buffalo interval is filled with very coarse sandstone at many places. Similar conditions were observed in the Allegheny here.

While in a general way the conditions were similar to those of the Allegheny, showing a gradually contracting area, yet the subsidence was such as to admit seawater to a much greater space. At the very beginning one finds at somewhat widely separated localities in West Virginia a marine fauna in the Uffington shale which rests directly on the Upper Freeport coal bed, while at most exposures the shale yields only impressions of land plants. Not enough information is available to justify any suggestion respecting the relations of the marine localities, which are confined to the easterly side of the great basin.

The Brush Creek limestone, separated from the Uffington shale by the Mahoning interval, is confined in its best development to the northeastern part of the area. It occurs irregularly in northeastern Ohio and is continuous in a not very broad area eastwardly and southeastwardly across Pennsylvania into western Maryland and northeastern part of the West Virginia coal field. It is wanting along the northern border in Pennsylvania as well as east from the Alleghenies. No trace of it appears in most of Ohio and it is wanting under the Cowrun anticline, in the central part of the basin; but a limestone at its place is present in the extreme southern part of the area in West Virginia. The fauna is distinctly marine and the distribution of the deposit leads one to look toward the east for its connection with the sea. The Cambridge limestone, on the other hand, represents an invasion by the interior, or Mississippian, sea, for as a marine limestone it prevails from Armstrong county of Pennsylvania westward into Ohio and thence southwardly into Kentucky. It is wanting in the interior area, but reaches the middle line of the basin in the southern part of West Virginia, in Cabell and Wayne counties, as

well as in Johnson county of Kentucky. Its area, narrow in Pennsylvania and northern Ohio, becomes much wider southward. On the east side of the great basin in Maryland and 90 miles from the nearest locality in Pennsylvania where the Cambridge is clearly recognizable, a marine limestone is found certainly not far from the Cambridge horizon, indicating continuance of communication with the ocean on that side.

The Ames limestone is not reported east from the Alleghenies in Pennsylvania, but is distinctly present in Indiana and Somerset of that state, whence it has been followed across Maryland into Barbour county of West Virginia. This limestone is shown farther west in Pennsylvania, wherever its place is exposed, south from the line of Cambria, Clearfield, and Jefferson counties, and it is equally persistent in Ohio, where, as in Pennsylvania, it is the most useful stratigraphical horizon, being midway between the Pittsburg and Upper Freeport coal beds. It is well shown in the central part of the great basin, under the Cowrun anticline, in Washington of Ohio as well as in Pleasants and Wirt of West Virginia; it is present in the southern portion in Wayne and Cabell counties, and it may be the Fourth Fossiliferous limestone of Kentucky. No borings with diamond drill have been made in the deeper portions of West Virginia and no statement is possible respecting its presence there. It has not been reported along the eastern outcrop south from Barbour county of West Virginia, but at Charleston one finds a limestone, without marine fossils, midway between the Pittsburg and Upper Freeport coal beds and, like the Ames, associated with deep red shale. At all exposures, except that near Charleston, the Ames carries a marine fauna, and at many places on both sides of the basin it rests on fossiliferous shale or, where that is wanting, on the Harlem coal bed. The fauna seems to differ slightly on the opposite sides, some forms characteristic of the Indiana-Illinois field being present on the west side, but wanting on the east side. It may be discovered, when the fauna has been studied thoroughly, that communication was open to the ocean on both sides. It is not improbable, as suggested by Doctor White, that the fossiliferous limestone of the Northern Anthracite field belongs very near the horizon of the Ames. That bed contains many forms obtained from the Conemaugh and in addition several which have not been reported from any other locality within the Appalachian basin; so that there one may have another problem respecting relation to the ocean.

With the Ames limestone, inroads of the sea practically ceased. Marine conditions unquestionably were repeated, but never for periods long enough for good development of animal invertebrate life. Limestones

appear frequently during the upper half of the Conemaugh, several of them widely, though irregularly, distributed, but in no case are they distinctly marine. Some are crowded with minute univalves of undetermined relations; others are associated with carbonaceous shales, filled with fragments of plants and fishes, which point rather to fresh-water conditions.

The most notable feature of the Conemaugh is the red and green shales, in color resembling those of the Catskill and Shenango but deeper. The greatest development is in west central West Virginia and the adjacent part of Ohio, where at times nearly the whole section is red shale. The greatest geographical expansion was just preceding the deposition of the Ames limestone, when the reds reached southeast nearly to the outcrop and northward to the outcrop in Pennsylvania; but they did not reach into northern Ohio and they are practically wanting east from the line of Chestnut hill in Pennsylvania. From that time to the end of Conemaugh the area contracted and reds occur in irregular patches. These beds frequently contain nodules of limestone, which, at least in the Pittsburg reds, underlying the Ames limestone, are usually fossiliferous. The red shales in some cases mark horizons elsewhere carrying limestone and they may indicate a marine condition.

The exceeding shallowness of the water and the long periods of quiet during the Conemaugh are indicated by the coal beds, which, though extremely thin, have great extent. The most remarkable is the Harlem, which underlies the Ames limestone. It rarely exceeds 15 inches, yet is present in much of Pennsylvania, Maryland, and Ohio, persisting in the interior of the basin within West Virginia, where it is brought up under the Cowrun anticline. The peculiarities of this and other Conemaugh coal beds are of much importance in any discussion respecting the accumulation of coal in beds, and they will be examined carefully in another connection.

Toward the close of the Conemaugh the streams bringing in materials had become sluggish and the deposits, except within limited areas, are fine in grain. The Monongahela began with a long period of exceedingly slow subsidence, during which the Pittsburg coal bed gradually extended across the northern part of the great basin and southward along the east and west sides; but from all sides it became thinner toward the central part of the basin and it is practically wanting in a great part of West Virginia and eastern Ohio, where it occurs only in widely separated patches. The bed may have been almost continuous around the basin. The singular uniformity of conditions and the extreme slow-

ness of the movement are shown by the structure of this great bed, persisting in such minute details as partings in tracts of thousands of miles and reappearing even in isolated patches within West Virginia.

The area of greatest subsidence during the Monongahela did not coincide with that of the earlier formations, as appears abundantly from comparison of sections along several lines. The deepest deposits of Allegheny and Conemaugh were at the north and east; not so in the Monongahela. Going west-northwest from the eastern outcrop in Maryland, the measurements are 250 feet in the Potomac basin, 316 in the Connelsville, 375 to 380 in Greene county of Pennsylvania, and 213 in Belmont county, on the western outcrop in Ohio. Along a south-southwest line near the middle of the basin one finds 150 feet in Allegheny county of Pennsylvania, 225 in northern Washington, 355 in southern Washington, 360 to 375 in Greene, and 428 in western Marion of West Virginia. Similar variations appear along a west-northwest line farther south in West Virginia as well as along a south-southwest line farther west in the basin. The greatest subsidence was in north central West Virginia, whence the thickness decreases in all directions. The change is due to differential subsidence, as the intervals between the important members of the section become thinner. The change bringing this about began after deposit of the Pittsburg coal bed, for that is not overlapped toward the outcrop by the higher beds; it certainly extends farther north than do some of the later beds. The absence of that coal bed in so large an area may be due merely to slight irregularities of the swampy surface, for in some parts of that area the underclay with a black streak above it marks the place of the bed.

With this change in place of chief subsidence there came clearly a farther contraction of the basin, while elevation at the north led to spreading out of sandstone along much of the northern border. This Pittsburg sandstone is not present in the eastern localities of Pennsylvania and Maryland, but is persistent in the Chestnut Ridge area of Fayette and Westmoreland counties, in that state, as well as southward along the eastern outcrop in West Virginia to the last exposure near Charleston, where Doctor White found it 70 feet thick. Evidently it prevailed along the western outcrop in Ohio, for it is present on the northwestern outcrop and also in the central counties along that line, where one is again much farther west than in the intervening counties. This sandstone becomes more and more indefinite from all sides toward the interior of the basin. The Sewickley sandstone, underlying the Upper Sewickley coal bed, is fairly persistent on the east side, but is wholly insignificant in Ohio. There, however, an important sandstone overlies the Upper Se-

wickley, not pebbly at the northwest, but coarse and often pebbly in southern Ohio. In Pennsylvania and northern Ohio a more or less persistent sandstone, the Uniontown, overlies the Uniontown coal bed, but ordinarily it is unimportant and many sections show little aside from shale in the interval. In West Virginia, however, a strip of coarse conglomerate, evidently at this horizon, crosses the state from east to west, passing through Lewis, Gilmer, Doddridge, Tyler, and Pleasants counties and extending into Washington, Morgan, and Athens of Ohio, where it is the 200-foot conglomerate of Professor Andrews. It is coarser in West Virginia than in Ohio. The strip is very narrow in the former state and fine-grained rocks replace the coarse material at a short distance north and south; but in Ohio the area is broader, as though additional material had been brought in from that side. This east-and-west line of coarse rock recalls those of the Beaver and Conemaugh in Pennsylvania and may be explained in the same way. The general distribution of coarse material indicates a rising border land and for the southwest a notable encroachment.

The limestone deposits of the Monongahela deserve more careful consideration than can be given here, under the limitations set for this description. These rocks vary greatly in composition. The Redstone is an impure limestone, yielding a fair lime when burned carefully; the Fishpot, when thin, usually resembles the Redstone, but when thick it is apt to contain some layers of cement rock; the Benwood has several beds of hydraulic limestone, even of cement rock, among its most persistent members, while some of the beds are so impure as to break into small angular fragments after continued exposure; the Uniontown and Waynesburg are rarely more than slightly magnesian.

Of the numerous limestones, only the Uniontown can be regarded as really persistent; it is present in western Pennsylvania and in Ohio at nearly every locality where its place is shown. The others may be regarded as confined to southwest Pennsylvania, the West Virginia panhandle, and the immediately adjacent part of Ohio. Their great development is between the Monongahela river at the east and the Ohio river at the west, where in considerable areas limestone and calcarous shale fill more than one-half of the interval between the Redstone and Uniontown coal beds. In all directions from this small area the limestone diminishes quickly and is replaced by shale and sandstone; toward the southwest only some thin streaks remain in West Virginia, and in some portions of that state those streaks seem to be replaced by red shale.

These limestones are spoken of commonly as merely calcareous muds, and that explanation of their origin was accepted tentatively on a pre-

ceding page. But it is insufficient. The enormous thickness in an area of almost 3,000 square miles, central in the northern part of the Monongahela area, as it now exists, can hardly be explained in this way, as there is no known source whence the calcareous mud could be derived by erosion or by solution. One is shut off completely from consideration of the Michigan Mississippian, for the Monongahela limestones disappear wholly in that direction long before the outcrop has been reached. Equally impossible is the supposition that they could have been derived from the West Virginia Mississippian far toward the southeast. That they accumulated as marls in fresh-water areas is equally difficult to believe, for the immense Benwood limestone on the Monongahela is equivalent to very nearly the same thickness of shale and sandstone within a very short distance. The magnesian beds, seemingly the most persistent, can hardly be regarded as fresh-water limestones. Marine origin seems questionable, owing to absence of marine invertebrates. It is true that no careful search for fossils has been made in these rocks; yet the beds have been measured at so many places that some forms should have been found, if such exist. Weathered surfaces of the harder layers in the Benwood occasionally show what bear close resemblance to sections of branching bryozoans, but in every case the fossil is replaced by calcspar and is unrecognizable. Fish remains, teeth, and spines of sharks occur, the most characteristic being *Ctenacanthus marshii.* These are certainly marine, and the specimens obtained were of such size as to show that the surroundings were not unfavorable. Additional evidence that the sea was not wholly shut out is the presence of *Solenomya* in shale above the Sewickley coal bed in Monongalia county of West Virginia. *Naiadites* occurs in the Uniontown limestone at Uniontown, Pennsylvania; but the ingress of seawater does not appear to have continued long enough to permit an invertebrate fauna to make its way. For the present, the origin of the limestones must be regarded as an unsolved problem.

Toward the close of the Monongahela the condition marking the later portion of the Conemaugh was reached once more. In by far the greater part of the area the deposits are fine in grain, and at the end the Waynesburg coal bed was formed, in the northern part of the basin, a bed of curiously multiple structure, which is retained. Like the Pittsburg, it is wanting in the interior region, but it seems to have reached irregularly southward to a long distance on each side.

The Washington opens with a plant-bearing shale like that overlying the Pittsburg, succeeded by a great sandstone, recalling in some respects the sandstones of the Rockcastle. As the area grows smaller in ascend-

ing, it becomes necessary for comparison to consider separately the lower and the upper portion of the Washington. The lower, extending from the Waynesburg to the Washington coal bed, is shown broadly. The length of the column along a west-northwest line from the eastern outcrop is 120 feet in Maryland, 135 feet in Fayette, and 180 in Greene of Pennsylvania, 117 in eastern Belmont of Ohio, and 100 feet at the western outcrop. Along a south-southwest line one finds 50 feet at the most northerly exposure in Pennsylvania, which increases gradually to 130 feet at the Greene County line and becomes 170 feet in Wetzel county of West Virginia, where well records are very numerous; and this 170 feet seems to be the interval in much of central West Virginia; but it decreases farther south. The upper portion, seen in much smaller area, shows similar variation. The full section is not found exposed anywhere east from the Monongahela in Pennsylvania, but in Fayette county an approximate measurement gives about 200 feet from the Washington coal to the Upper Washington limestone; westwardly in Greene the interval increases to 240, and then to 300 feet, while at Moundsville, on the Ohio river, it has decreased to 244 feet. Along a south-southwest line it is 110 feet at the most northerly exposure, increases steadily to 190 feet at the northern line of Greene, and across that county it increases to 308 feet in West Virginia. The formation thus increases from 160 feet in northern Washington of Pennsylvania to above 480 feet in the northern counties of West Virginia, thus showing a continuance of the Monongahela conditions, with the greatest subsidence in north central West Virginia.

The sandstones tell the story of steadily contracting area. The Waynesburg sandstone is persistent in Maryland, in most of Pennsylvania, as well as southward in West Virginia for a long distance. It is massive and at times pebbly, though, like all sandstones of the higher formations, it is sometimes replaced abruptly by shale. In Ohio, along the northwestern border, it is not a coarse sandstone, but farther south it becomes coarser and more prominent, being Professor Andrews's upper sandstone and conglomerate. Thence southeastwardly along the southern border, in Jackson and Putnam of West Virginia, the rock marking this horizon is a coarse sandstone, with quartz pebbles sometimes an inch in diameter. In the interior portion of West Virginia records of oil borings show sandstone persistent in this interval except in a small area. The Waynesburg is the first sandstone of wide extent in the interior region. No notable sandstone above the Waynesburg appears in Pennsylvania, except that underlying the Upper Washington limestone, which is confined to the borders of the remaining area and disappears southwardly. Below

this one finds local sandstones, but they are unimportant. In the southern portion of the basin, on the contrary, the interval above the Washington coal bed is characterized by great sandstones, the Marietta of Doctor White, which appear in their greatest development toward the southwest outcrop, though they are prominent features across West Virginia, extending northward to midway in the state.

The limestones of the Washington are quite as perplexing as those of the Monongahela and they are confined to a smaller area. They attain great thickness in central and southern Washington of Pennsylvania, become comparatively insignificant southward in Greene county, and practically disappear very soon in West Virginia. Limestone is most abundant above the Washington coal bed, and in many places the mass is largely calcareous shale. Few layers yield good lime, but the Upper Washington limestone is ordinarily very good. Fossils of any sort are very few, but occasionally one finds a great abundance of bivalve crustaceans, usually thought to be of fresh-water types. Fish remains occur plentifully in shales associated with some of the limestones, and they, too, are probably fresh-water, as some of the genera are the same with those found in the cannel of Linton, Ohio. Inroads of the sea are not clearly shown. A shale containing some marine forms is reported from one locality in West Virginia, but this is at the very bottom of the formation. One of the Washington limestones shows obscure markings like fragments of brachiopods, but they are wholly indefinite and the evidence seems to point to final exclusion of the sea from the contracting basin. The limestones of the Washington bear much more resemblance to calcareous muds than do those of the Monongahela, but it is difficult to discover the source whence they were derived.

During the Washington the crustal movements were sluggish within the basin of deposition. Thin streaks of coal extend over great areas, many of them showing complex structure; but toward the close the movements became more pronounced, and during the early portion of the Greene the deep portion of the basin was confined to Greene county of Pennsylvania and a narrow strip adjoining at the west in West Virginia. A comparison of sections shows that in southern Washington county, following the Greene County line eastward, the interval from the Upper Washington to the Nineveh limestone varies from 150 to 180 feet, each of these measurements being obtained twice, those of 180 being separated by one of 150, showing two shallow troughs cut by this east-and-west line; but within half a dozen miles southwardly, in the central part of Greene county, the interval increases, becoming 300 to 313 feet with a number of new limestones and coal beds. The chief

increase is in the lower portion, between the Upper Washington and Jollytown limestones, but there is a marked increase in the upper portion also. This lower interval, 130 to 140 feet in the deepest area, of Greene county, becomes only 30 feet at the West Virginia line midway in the basin, and the interval, Upper Washington to Nineveh, seems to be about 200 feet thence south-southwestwardly for many miles.

That the area of deposit was contracting rapidly appears also from the sandstone deposits. The important Fish Creek sandstone is a notable bed in Greene county and extends for a long distance in West Virginia. The Nineveh sandstone, well cemented like the other, is persistent from its northern outcrop, in southern Washington county, across Greene into Wetzel of West Virginia, beyond which no information respecting it is available. The Gilmore sandstone, a poorly cemented massive rock, remains on high knobs in Greene county, as well as far southwestward in West Virginia, while the highest rock of the series is a massive sandstone of which only isolated patches remain on knobs in West Virginia. All of these are along the middle line of the basin, where during deposition of all formations prior to the Washington the sandstone intervals were usually filled with shale. The sources of supply were much nearer than in earlier periods. But the basin, though rapidly losing in width, still extended for not less than 200 miles in north-northeast to south-southwest direction when the Nineveh limestone was laid down.

The limestones, except the Nineveh, are of little importance. No conclusions respecting the highest limestones can be offered, as those beds remain only on very high knobs and in small patches; yet they are of no little interest, in that they extend southward beyond most of the lower limestones and yield good lime. The Nineveh limestone is persistent throughout the whole region in which its place is reached. It has been followed by Doctor White from southern Washington of Pennsylvania to Jackson county of West Virginia, about 140 miles, and it is present at localities on the Ohio river, where its place is reached in Tyler of West Virginia and Washington of Ohio. Even at its most southerly exposure it has 30 feet of limestone and calcareous shale.

No marine forms have been reported from any place. There is much in the character of the Nineveh limestone to lead one to expect such forms, but none has been obtained. Animal remains of all sorts are rare, but Doctor R. P. Whitfield has described some pulmonate forms from Greene beds near Marietta, Ohio, and a few lamellibranchs of doubtful relations have been obtained in Pennsylvania and West Virginia. There is no evidence that the sea actually entered the area in which rocks of the Greene formation remain.

The Red beds retained their importance apparently to the end within the half dozen interior counties of West Virginia and Ohio, and twice during the Monongahela the area showed a very considerable expansion, though in neither case equaling that of the Washington or lower reds of the Conemaugh and in each very much less than that of Pittsburg reds of the same formation. After the deposition of the Uniontown coal bed their area diminished, and during the Washington and Greene the reds became less and less important, appearing at last in, for the most part, thin and rather widely separated deposits, though occasionally, as in Marshall of West Virginia and northern Greene of Pennsylvania, they attain considerable local importance.

In reviewing the conditions within the north central part of the basin, one is led to believe that the loss by erosion is much less than has been supposed. From the crest of Chestnut ridge, in Fayette county of Pennsylvania, the whole of the Carboniferous has been removed and the Chemung rocks are exposed at several places along the summit; but within 5 milles toward the west the section reaches almost to the top of the Washington formation, while at 20 miles farther, beyond the broad valley of the Monongahela river, one finds the highest beds of the Greene. It seems wholly probable that the Gilmore sandstone is but a few hundred feet below the last deposit made in the Appalachian basin.

Notes on the Palæontology of the Pennsylvania

THE FAUNA

Comparatively little attention has been paid to the Pennsylvania fauna. When the early surveys were made, fossils were to most geologists little more than interesting curiosities; during prosecution of the later surveys, the urgent necessity for prompt determination of mineral resources left little time for collecting fossils, which indeed seemed hardly necessary, as the fossiliferous horizons are comparatively few and the forms observed in them appeared to be identical for the most part with those described in the Illinois and other volumes published by western states. It results that for comparison one has only the partial lists given by Messrs Meek, Whitfield, White, and Stevenson.* The forms thus far reported, with their horizons, are:

* F. B. Meek: Rept. Regents of West Virginia University for 1870, pp. 66-73; Rept. progress of Geological Survey of Ohio for 1870, p. 79; Palæontology of Ohio, vol. ii, p. 326.

R. P. Whitfield: Palæontology of Ohio, vol. vi, p. 482.

I. C. White: Second Geological Survey of Pennsylvania, Q, p. 62; Q Q, p. 46, 61; Q Q Q, p. 25.

J. J. Stevenson: Trans. Am. Phil. Soc., vol. xv, pp. 22, 28; Second Geological Survey of Pennsylvania, K K K, p. 309; Geology of Ohio, vol. iii, pp. 207, 222.

1. Mercer limestones.
2. Vanport limestone.
3. Uffington shale.
4. Brush Creek limestone.
5. Ames limestone in West Virginia and Pennsylvania.
6. Ames limestone in Ohio.
7. Lower Coal Measures of Ohio, horizon not given.

Lophophyllum profundum Ed. & Haime		2	3	4			
Hydreionocrinus mucrospinus McC. sp		2	3	4			
Eupachycrinus mooresi Whitf. sp							7
Cyathocrinus somersi Whitf							7
Archæocidaris wortheni H		2					
Pentremites pyriformis		2					
Erisocrinus sp			3	4			
Fenestella sp.				4			
Polypora sp.	1						
Septopora biserialis Swall sp	1	2					
Cystodictya carbonaria M							7
Prismopora serrata M. sp							7
Discina meekana Whitf						6	7
Chonetes mesolobus N. & P	1	2		4			
Chonetes smithii N. & P				4	5	6	
Chonetes granulifer O					5	6	
Chonetes sp.	1						
Productus equicostatus Shum	1						
Productus nebrascencis O	1	2	3		5	6	
Productus semi-reticulatus Martin	1	2			5	6	
Productus punctatus Martin	1					6	
Productus longispinus Sow	1	2		4	5	6	
Productus cora D'Orb	1	2	3	4	5	6	
Productus pertenuis M				4			
Orthotetes crassus M. & H. sp	1	2	3	4	5	6	
Meekella striato costata Cox sp					5		
Rhipidomella pecosii Marcou sp					5	6	
Pugnax uta Marcou sp						6	
Spirifer cameratus Norton	1	2		4	5	6	
Spirifer rocky-montani Marcou	1	2		4			
Squamularia perplexa Swall. sp	1	2			5	6	
Ambocœlia planoconvexus Shum. sp					5	6	
Spiriferina kentuckensis Shum						6	
Hustedia mormonii Marcou sp						6	
Seminula subtilita H	1		3	4	5	6	
Lima retifera Shum				4	5		
Pernopecten aviculatus Swall. sp	1						
Nucula ventricosa H		2	3		5	6	
Nucula (?) anodontoides M					5		
Nucula parva McCoy					5		
Yoldia carbonaria M			3		5	6	

Yoldia stevensoni M.					5		
Leda bellistriata Stevens		2					
Leda bellistriata var. *attenuata* M.					5		
Leda arata H.			3				
Macrodon tenuistriatus M. & W.	1						
Macrodon obsoletus M.	1	2			5		
Schizodus cuneatus M.	1						
Schizodus sp.			3		5		
Avicula longa Geinitz	1						
Aviculopinna Americana M.	1	2			5		
Pseudomonotis sp.					5		
Myalina subquadrata Shum.				4	5		
Myalina recurvirostris M. & H.	1						
Myalina swallovi McC.	1						
Deltopecten occidentalis Shum. sp.	1				5		
Acanthopecten carboniferus Stevens. sp.	1	2	3	4	5		
Aviculopecten interlineatus M. & W.	1						
Aviculopecten whitei M.		2					
Aviculopecten hertzeri M.	1		3	4			
Aviculopecten coxanus M. & W.	1						
Aviculopecten sp.	1						
Placunopsis recticardinalis M.	1						
Posidonomya fracta M.	1						
Pleurophorus tropidophorus M.	1						
Pleurophorus sp.					5		
Solenomya anodontoides M.	1						
Solenomya radiata M. & W.		2			5		
Astartella newberryi M.	1						
Astartella varica McC.	1						
Astartella vera H.				4			
Astartella concentrica		2	3	4	5		
Edmondia aspenwallensis M.				4	5		
Edmondia 2 sp.	1						
Pleurophorella costata M. & W.							7
Pleurophorella sp.					5		
Cypricardinia carbonaria M.	1						
Euphemus carbonarius Cox sp.		2	3	4	5		
Patellostium montfortianus N. & P. sp.		2	3	4	5		
Bellerophon percarinatus Con.		2	3	4	5		
Bellerophon stevensanus		2			5		
Bucanopsis marcouiana Geinitz sp.					5		
Euomphalus catilloides Con. sp.		2	3	4	5		
Naticopsis tortum M.		2					7
Sphaerodoma primigenius Con. sp.		2	3	4	5	6	
Soleniscus brevis White		2	3		5		
Soleniscus klipparti M. sp.							7
Soleniscus regularis Cox sp.							7
Loxonema plicatum Whitf.							7

Polyphemopsis peracutus M. & W.	2	3	4			
Phanerotrema grayvillense N. & P. sp.	2	3		5		
Pleurotomaria carbonaria	2	3	4			
Worthenia speciosa M. & W. sp.		3				
Worthenia tabulata Con. sp.				5		
Orthoceras cribrosum Geinitz	2	3	4	5		
Tainoceras occidentalis Swall. sp.	2		4	5		
Nautilus ortoni Whitf.						7
Nautilus subquadrangularis Whitf.						7
Phillipsia sangamonensis M. & W.*		3				

The Monongahela and higher formations, so far as known, have yielded very few forms: a *Solenomya* from shale above the Sewickley coal bed, two species of *Naiadites* from the Uniontown limestone, and undetermined ostracoids from some of the limestones make up the list.

The number of species recorded is considerable, but the distribution as given in the table shows the scantiness of material for comparison, for it is very certain that the vertical range of some of the species is much greater than represented. No locality has been studied with any degree of care, except a little area near Morgantown in West Virginia, where was obtained the collection examined by Mr Meek in 1870. The Ames limestone fauna alone has been observed on both sides of the basin, and even this only in the northern portion. There, however, one interesting feature has been noted, for in Ohio four species occur abundantly, which are very common in the Mississippi Valley areas, but are wholly unknown at any of the numerous localities where the bed has been examined along the east side of the Basin. There is no information on the western border respecting the fauna of the Putnam Hill and Vanport limestones or that of the shales overlying the Middle Kittanning coal bed. Until proper study of the fauna at each horizon has been made, no opinion can be expressed as to the value of the fauna for correlation. The forms already reported are for the most part only those which are the most familiar, with extended vertical as well as geographical distribution.

Some lists of fossil invertebrates by Messrs Meek, Prosser, Bennett, and Hall,† giving forms obtained from the higher Carboniferous beds along the Missouri river in Kansas and Nebraska, afford opportunity for comparison with the northern part of the Appalachian basin.

Mr Meek's fossils came from the higher beds of the Upper Coal

* The writer is under obligation to Mr George H. Girty, who has corrected the generic names in this list; but Mr Girty is not to be held responsible for any errors, as he has not had the opportunity to read the proof.

† F. B. Meek: Final Rept. of U. S. Geol. Survey of Nebraska, pp. 124-127.
Bennett and Hall: University of Kansas Geol. Survey, vol. iii, pp. 68-72.
C. S. Prosser: The same, vol. ii, p. 59.

Measures of Nebraska. Of the 43 species common to his list and that from the Appalachian, only 7 are confined to the Upper Coal Measures of Illinois, the others occurring throughout the section in that state; but of those 7 one finds that in the Appalachian 3 begin at the Mercer horizon, 1 at the Brush Creek, and 3 at the Ames. The short lists by Messrs Bennett and Hall of forms from the Upper Coal Measures of Kansas show 18 of the 43 species, all of which except 5 are found as low as the Vanport; of those, 2 are in the Brush Creek and 3 in the Ames. In Professor Prosser's list of Permian forms, 5 are in the Appalachian list, of which 2 begin in the Maxville, 1 in the Mercer, 1 in the Vanport and 1, *Yoldia subscitula,* is so near to *Yoldia stevensoni* from shales underlying the Ames, that the latter name is little better than a synonym. As far as the present imperfect information goes, the Allegheny and Conemaugh seem to be equivalent to the Lower Coal Measures of the Mississippi valley; further than that, one may not go.

Comparatively little is known respecting the vertebrate fauna of the Pennsylvanian, such studies as have been made being confined practically to forms occurring at a single locality. Professor Newberry * described fish remains from the Upper Freeport and Tionesta coal beds of Columbiana county, Ohio, with a few forms obtained elsewhere. According to his reference of these forms, there are elasmobranchs, ganoids, and lepidosteids present, of which 20 are peculiar to one locality. Three elasmobranchs and lepidosteids have a wider distribution. *Ctenobranchus marshii* Newb. was described from Allegheny beds near Zanesville, Ohio. Doctor Newberry identified with this species, whose associations are wholly marine, a spine from the upper Monongahela, obtained near Washington, Pennsylvania, where it is accompanied by *Helodus* and *Lophodus.* The features show no change whatever. *Petalodus, Peripristis, Deltodus,* and *Lophodus* were found in shale underlying the Ames limestone near Morgantown, in West Virginia, and *Petalodus* occurs in the Ames of northern Ohio. Large scales, belonging to *Rhizodus,* were found by Doctor White in shale accompanying the Middle Washington limestone of Washington county, Pennsylvania.

Professor Cope † described 35 species of batrachians, all except one confined to the Upper Freeport coal bed at Linton, Columbiana county, Ohio. No remains of this class have been reported elsewhere, though one finds occasional mention of what appears to be footprints.

THE FLORA

The earliest attempt at systematic study of American Coal Measures

* J. S. Newberry: Palæontology of Ohio, vol. ii, pp. 41 et seq.
† E. D. Cope: Palæontology of Ohio, vol. ii, pp. 351 et seq.

plants was in 1854, when Professor Newberry* described without figures a large number of forms collected by him from roof shales of the Sharon coal bed in northern Ohio. Simultaneously Mr Lesquereux † was engaged in the study of remains collected within the Anthracite region of Pennsylvania; but his results were not announced until 1856, when they appeared in preliminary form, the final publication being in 1858. His collections were incomplete and the locality labels, apparently, were not always correct; but the work was marked by great care and his figures by exactness. Unfortunately the species, of which the range was known only imperfectly, were used in correlating the coal beds of Pennsylvania and Kentucky, with results so erratic that for a long time the testimony of plant remains was thought to be of little service in correlation. In 1873 Professor Newberry ‡ described and figured a few forms from the Sharon horizon, one of which, belonging to a new genus, seemed to be somewhat closely allied to *Tæniopteris;* and two years later Professor Andrews § gave figures and descriptions of 17 new species obtained in Perry county of Ohio, at the very bottom of the Ohio Coal Measures as then limited. This flora is described as having close affinity with the Devonian, while, like that described by Newberry, it yields a new genus, thought to belong to the Tæniopteridæ. In the interval Professor Fontaine || had collected a few forms from the Sewell coal bed of New river, West Virginia, and had emphasized the Devonian aspect of the flora. In 1876 Mr Lesquereux ¶ published, without figures, a list of species obtained in eastern Alabama from the lower portion of the Coal Measures of that state, and recognized the forms as older than the "Millstone grit," apparently the same with the Sharon conglomerate, which he seems to have regarded as the basal member of the Upper Carboniferous. He lays stress upon the intimate relationship of some of the forms to Devonian types. In 1880 was published Mr Lesquereux's** descriptive catalogue of Coal Measures plants, in which are enumerated 599 species and varieties then known in the United States. A table showing the vertical distribution of the forms brings out clearly the fact that the flora of the New River beds is not related to that of post-Sharon beds in Ohio, and that it has much in com-

* J. S. Newberry: Annals of Science, vol. ii.

† L. Lesquereu: Proc. Bost. Soc. of Nat. Hist., Geology of Pennsylvania, vol. ii, pp. 837-884.

‡ J. S. Newberry: Palæontology of Ohio, vol. i, pp. 359.

§ E. B. Andrews: Palæontology of Ohio, vol. ii. p. 415.

|| W. M. Fontaine: The Great Conglomerate. Am. Jour. Sci., III, vol. vii, p. 574.

¶ L. Lesquereux: Geological Survey of Alabama, Rept. for 1875, p. 75.

** L. Lesquereux: Description of the coal flora of the Carboniferous formation in Pennsylvania and throughout the United States, vol. i.

mon with that of the lower beds in Tennessee and southward. Separate lists of forms collected at many localities in Pennsylvania, Ohio, Kentucky, Tennessee, and Alabama afford means for a closer comparison, which is made in a chapter on Stratigraphical Distribution. This work marks a great advance in application of plant remains in problems of correlation and an equal advance in methods of studying the remains themselves.

In the same year Professors Fontaine and White* published figures and descriptions of species obtained from the roof and partings of the Waynesburg coal bed, together with some from other horizons in the Monongahela and higher formations. Here one finds a serious attempt to utilize the testimony of plant remains in broad correlation of horizons. The effort in the introductory chapter to compare floras characterizing the several formations exposes the neglect of which students had been guilty throughout the Appalachian field, for the collections were so scanty that the authors had to be content with, for the most part, only general statements. Comparisons were made between plants collected from the upper part of the Rockcastle on New river of West Virginia, those listed by Lesquereux from Alabama, and the forms obtained in Ohio by Newberry and Andrews, and the important conclusion was drawn that the Pottsville flora has a genuine facies, distinguishing it from those of formations below as well as from that of the Allegheny above. Material for comparison was almost wholly wanting from the Allegheny, Conemaugh, and Monongahela formations, being confined for each to one or two localities. The forms described in this volume were obtained chiefly from the roof shales of the Waynesburg coal bed at Cassville, in West Virginia, 4 or 5 miles south from the Pennsylvania line; but small collections had been made from that horizon elsewhere in West Virginia and from Greene county of Pennsylvania. The peculiar feature noted at Cassville is that the plants are "distributed in the most singular manner, they being grouped in colonies, which are confined within very narrow limits; so that the plants which abound at one opening for coal will be entirely wanting in another only a few hundred yards distant, where we find instead of them a collection of species so different that it might well characterize a different horizon."

In all, 107 species and varieties are given as obtained from the Cassville shale and higher horizon. Of these, 56 are peculiar to the Cassville shale, 15 are common to the Cassville shale and that overlying the coal bed in Doddridge county, taken by the writer to be the Uniontown,

* W. M. Fontaine and I. C. White: The Permian or Upper Carboniferous flora of West Virginia and southwestern Pennsylvania.

but at that time believed by all to be the Waynesburg; 14 are peculiar to the Doddridge horizon; 9 are confined to the Washington coal or higher horizons, while 11 have a great vertical range, some surviving from the Doddridge shale to 600 or 800 feet above the Waynesburg coal bed.

The final chapter of the work is an elaborate comparison of this flora with European forms, including also a comparison of the physical changes closing the Carboniferous of this area with those closing the Carboniferous and Permian of Europe. The conclusion reached by the authors is that the Upper Barrens of the Appalachian field (Washington and Greene formations) are of Permian age, and this is based on evidence from identical or allied species, the decadence of Coal Measures forms, the introduction of types characteristic of later formations as well as on that from physical contrasts between the Upper Barrens and the preceding formations. They find that 28 species are common to the Upper Barrens and the Permian of Europe, of which 12 have been found in the United States Coal Measures, while 2 are exclusively Permian and 4 others are closely allied to European Permian forms.

The importance of this communication was recognized at once, but the conclusions were not accepted as final, chiefly because of the paucity of known material from the Allegheny, Conemaugh, and Monongahela formations which might be used for comparison. No further investigation of the problem was made for almost 23 years, until Mr David White, after study of extensive collections from the earlier formations, undertook preliminary revision of the horizons discovered and discussed by Professors Fontaine and I. C. White. The results of this revision were published in 1903.* The collections, made at the typical as well as at other localities and horizons, led Mr White to place the forms in five categories:

a, those characteristic of the Rothliegende or higher formations of the Old World; *b,* those closely allied to Permian types; *c,* those whose habit or facies suggests a late date; *d,* those of Mesozoic aspect; *e,* Coal Measures type.

In the first category Mr White places 3 species of *Callipteris,* one each of *Goniopteris, Pecopteris, Alethopteris, Odontopteris, Caulopteris, Equisetites,* and *Sigillaria,* with 2 species of *Sphenophyllum;* in all, 12 species. In the second are also 12, but the author states that the number might be extended according to the personal equation of the observer or to the amount of material available for comparison, while, at best,

* D. White: Permian elements in the Dunkard flora. Bull. Geol. Soc. Am., vol. 14, pp. 538 et seq.

evidence of this class is of subordinate value, some of the forms placed here belonging with equal propriety also in succeeding categories. He places in the third category 14 forms, all of them new and unknown elsewhere; these in their general facies suggest a later date than Coal Measures. He places 9 forms in the fourth category and regards their presence as an interesting and important argument for Permian age, for they are types whose nearest relatives are Mesozoic or whose facies strongly suggests types characteristic of Mesozoic. Here are species of *Equisetites, Saportæa, Jeanpaulia,* and *Tæniopteris,* as well as of other genera. On the other hand are forms belonging to the fifth category, a considerable element of Coal Measure species, whose presence is invincibly against reference of the beds to a level above the basal Permian. The number of species common to the Dunkard and lower formations, only 22 at the time when Professors Fontaine and I. C. White published their work, is now known to be much greater, as the Monongahela flora has been studied in part. Mr White enumerates 29 common forms which are of ordinary occurrence in the Coal Measures, these being only the more widespread forms, more than one-half of them appearing frequently in the Allegheny or Conemaugh.

Mr White finds in the Dunkard plants a transitional flora, such as should be expected in a region where conditions remained practically the same. The boundary between Coal Measures and Dyas is to be determined by the appearance of characteristic Rothliegende species rather than by the presence of persistent Coal Measures types. In western Europe the presence of *Callipteris,* simple-fronded *Tæniopteris, Callipteridium* of the *gigas* or *regina* type, and the genus *Walchia* in a flora consisting largely of forms common to the Coal Measures is regarded as sufficient evidence of Rothliegende age, though *Callipteris conferta* and even *Walchia* may appear lower down. In the Appalachian region a small form of *Callipteris conferta* appears at the horizon of the Lower Washington limestone, while the typical larger form, with *Callipteridium gigas* and others, is unknown below the Dunkard coal bed. The evidence of Rothliegende age for beds below the Lower Washington limestone consists in the presence of *Equisetites rugosus* and several less important forms and of some others which have Mesozoic or Permian aspect; but these latter are extremely rare, having been found only in a single coal drift, though careful search has been made for them elsewhere.

Mr White regards the beds below the Lower Washington limestone as containing a transitional flora and not distinctly Rothliegende, but above that limestone the flora becomes increasingly characteristic. As in that

limestone is the first appearance of *Callipteris conferta,* he thinks the lower limit may be drawn safely at that horizon. The flora of the upper Dunkard is to be compared with the Stockheim and Cusel beds in Germany and the series in the basin of Brives in France. None of the characteristic coniferous genera, *Ullmannia, Tylodendron, Walchia,* occurs in Dunkard beds, though all are in Prince Edward island and *Walchia* is reported from Texas; and similarly many genera of ferns characterizing the Rothliegende of Europe seem to be wholly unrepresented.

In connection with Mr White's conclusions, it is well to recall some relations noted in preceding pages. The general physical conditions during Allegheny and Conemaugh were practically the same; for, while the basin was contracting, there was no material variation in character of the movements; but with the beginning of the Monongahela the area of greatest subsidence was shifted a hundred miles and the new condition remained unaltered throughout the Monongahela and Washington, which in this respect are one as the Allegheny and Conemaugh are one. A notable change occurred at the Washington, and Mr White has shown that the strongly marked lower Rothliegende flora makes its appearance near the bottom of the Greene formation.

After the publications in 1880, no others, aside from a supplement to Mr Lesquereux's catalogue, appeared until 1894, when Mr White presented a discussion, which, like that by Fontaine and I. C. White, marks a stage in the development of paleobotanic study within the United States. In this paper * the term "Pottsville" is applied to beds extending from the base of the Pennsylvanian to and including the Nuttall sandstone, which passes under New river at Kanawha falls, this use of the term being in accord with usage then prevailing for that region; it is equivalent to Rockcastle. The discussion was based on study of collections made by the author at 12 horizons whose relations were determined by his stratigraphic work along New river. He availed himself of previous studies by Professor Fontaine and of collections made away from the river by Mr M. R. Campbell, whose stratigraphic work left no room for doubt respecting relations of the localities.

The lowest two horizons seem to belong to the Mississippian, but the third, at 375 feet from the bottom, yielded 4 forms characterizing the Pocahontas coal bed at the Virginia-West Virginia line, 75 miles away. Soon after this determination was announced, Mr Campbell proved the stratigraphic equivalence of the horizons. The fifth horizon, that of

* D. White: The Pottsville series along New river, West Virginia. Bull. Geol. Soc. Am., vol. 6, pp. 303-320.

the Quinnimont coal bed, about 800 feet from the bottom, yielded 40 forms, which were compared with those collected at localities in Ohio, Tennessee, and Alabama. One form is common to the Pocahontas, 10 are in Alabama, and one is allied to a form described by Newberry from Ohio. About one-third of the species are of such vertical range as to be valueless for correlation, but nearly one-half of the forms or their varieties are confined definitively to the small middle part of the section, in which one finds the Horsepen coal beds farther south in Virginia. The eighth horizon, about 1,175 feet from the bottom, is that of the Sewell coal bed. At all localities the forms collected resemble closely those obtained from the Sewanee, Rockwood, and Tracy mines of Tennessee so closely that the author regarded the horizon as one throughout—a conclusion reached ten years afterward by Stevenson on purely stratigraphic grounds and without any reference whatever to Mr White's researches. The eleventh horizon, 1,500 feet from the bottom, is in the Nuttall sandstone, where 10 forms were obtained—a flora whose preponderating elements are characteristic of the Sharon coal bed in Ohio.

Mr White's correlations were very important. He found that the Sharon flora was confined to the highest portion of the section, and was led to assert that the great mass of sediment in the New River region and southward was older than the Sharon sandstone of Pennsylvania and Ohio, thus confirming the observation made 20 years before by Professor Andrews and overlooked by all students, because made incidentally and buried in a paper referring to other matters. But Mr White was able to extend the generalization to the Anthracite fields of Pennsylvania. The forms from the bottom of the thick sections of Pottsville have much in common with the Culm or Lower Carboniferous series of the Old World, while those from the middle present the general facies of the Ostrau-Waldenburg flora of Moravian Silesia.

These conclusions were wholly at variance with those reached by stratigraphers who had studied the Coal Measures of Pennsylvania and West Virginia. Six years later Mr White published another paper, also preliminary, in which the floras of various horizons in the Allegheny formation of Pennsylvania were compared with those of the Kanawha formation of West Virginia. These had been regarded by most of the stratigraphers as equivalent, though, as stated on a preceding page, the tracing was incomplete, being interrupted by a space of about 60 miles in northern West Virginia—a space where, as already shown, notable changes take place in both Allegheny and Beaver and in which the Rockcastle has its northern boundary.

Mr White's* discussion was based on study of collections made by himself from the Clarion, Kittanning, and Freeport groups of Pennsylvania as well as from the upper and lower portions of the Kanawha group, this latter term being applied to the rocks above the Nuttall sandstone up to and including the Stockton coal bed, underlying the Kanawha Black Flint. The study is reported in detail, full lists of plants at each horizon being given and their relations compared closely. It is necessary here to note only the author's conclusions.

Some forms are common to the lower Kanawha and the Allegheny, but they are either those of wide vertical range or such as originate in the upper zone of the Pottsville as now understood. A very large proportion of the forms which can be identified positively are either the same with upper Pottsville (Beaver) forms or are modifications of them. The plant life of the lower Kanawha is distinct from that of even the Clarion or lower Allegheny, not only in the different forms of ferns, but also in the more important relations of the flora as a whole. The fern elements of the Pennsylvania Allegheny are essentially different from those of the lower Kanawha and are in contrast with those below the Homewood sandstone (top of Beaver) of western Pennsylvania and below the Buck Mountain conglomerate in the Southern Anthracite field. The flora of the Freeport group is allied to that of the Upper Coal Measures of Pennsylvania or the Middle Coal Measures of the Old World; even that of the Clarion group is still bound to the higher floras and is comparable to the Middle Coal Measures of Britain, the upper portion of the Westphalian series; but the floral associations in the lower half of the Kanawha are almost totally lacking in characteristic elements of the Allegheny flora. Many of its elements are slight modifications of types in the West Virginia "Pottsville" (Rockcastle) and in the Southern Anthracite field, while the greater part of the rest are closely allied to Pottsville plants elsewhere or are unfamiliar forms. The lower Kanawha is comparable to the Westphalian or Lower Coal Measures of European basins. It is an elaborate connecting link between the typical Pottsville or Millstone grit flora and the Clarion flora of the Allegheny.

The flora of the Stockton coal bed, or upper Kanawha, on the contrary, shows a large proportion of forms identical with those found in the Allegheny valley; it is a typical Allegheny flora. Absence of the higher pecopterids as well as the proportion and range of the identical forms bespeak for the Stockton flora a place probably not higher than the Clarion

* D. White: Relative ages of the Kanawha and Allegheny series as indicated by the fossil plants. Bull. Geol. Soc. Am., vol. 11, pp. 145-178.

group of the Allegheny in Pennsylvania.* Collections from beds above the Black Flint yield floras typical of the higher Allegheny groups.

This paper contains important generalizations respecting isostatic movements in the southern Virginia region, anticipating in full much that has been given on preceding pages respecting geographical changes. The conclusion is reached that the Allegheny formation shows no extraordinary expansion in the Kanawha region, and that the Conemaugh retains its Pennsylvania thickness. Detailed information published after the appearance of Mr White's paper shows that the Allegheny, so far from thickening on the Kanawha, is thinner there than on the Allegheny river of Pennsylvania.

In the same year appeared a delayed paper by Mr White,† referring to the Anthracite region. This discussion is based on a careful stratigraphical study of the Pottsville in the Southern Anthracite field, whereby many indefinite conceptions of the relations, especially in the western part of the field, were corrected. During this study collections of plants were made in many localities which were compared with each other and with those obtained elsewhere within the Appalachian basin. The conclusions, like those in the other papers already cited, were preliminary and subject to revision in a monograph of the Pottsville flora which has not been published.

The type locality is at Pottsville, in the eastern part of the field, where a detailed section was obtained. Plants were collected at 41 places, covering the whole field, and 14 plant horizons were discovered at the type locality, the highest being about 200 feet below the Buck Mountain coal bed, long taken as the conventional base of the Allegheny. Another plant bed is at 43 feet below the Buck Mountain, the interval being filled with conglomerate and coarse sandstone, while an abundant flora is present in the roof shale of that coal bed. The study of collections obtained at Pottsville enabled Mr White to divide the column at about 700 feet below the Buck Mountain. The lower division contains plants characterizing the Lower Lykens Valley coal beds, Coal 4 and lower, at the westerly end of the field; a transition flora appears in three beds, 640 to 570 feet below the Buck Mountain, and an Upper Lykens flora, Lykens coals 2 and 3, is present up to about 375 feet below the Buck Mountain, the higher plant bed underlying about 100 feet of conglomerate; while in beds at 245 and 210 feet below the Buck Mountain is a higher flora,

* Mr White in a later paper gave reasons for placing this flora at an even lower horizon, possibly in the Pottsville.

† D. White: Fossil floras of the Pottsville formation in the Southern Anthracite coal field of Pennsylvania. 20th Ann. Rept. of U. S. Geol. Survey, pp. 755-930.

transition to that of the Buck Mountain and partaking in some respects of features characterizing the Allegheny flora.

In correlating these floras with those from other portions of the Appalachian basin, Mr White recognizes in the lower part of the Lower Lykens division forms wholly characteristic of the Pocahontas coal in the Virginias and occurring there, as in the Southern Anthracite field, with very narrow vertical distribution. The upper portion of this Lower Lykens division is closely related to the Quinnimont or middle portion of the New River section, and the correlation is clear for that as for its equivalent in Kentucky, Tennessee, and Alabama. The Upper Lykens flora is even more sharply characteristic. The elements of the flora in the roof of Lykens 3 are so preponderatingly identical with those in the roof of the Sewell coal bed in West Virginia and of the Sewanee in Tennessee that Mr White regards those coal beds as practically contemporaneous. As has been stated already, the stratigraphic study confirmed Mr White's correlation of the Sewell and Sewanee horizons; those localities are separated by an interval as great as that between the Sewell and Lykens Valley localities. The highest flora, 245 and 210 feet below the Buck Mountain, that of Lykens coal 1, is nearly allied to the flora of the Mercer coal beds and possibly contemporaneous with a flora in the Gladesville sandstone of southwest Virginia, as well as in Breathitt county of Kentucky, which accords closely with stratigraphic determinations in Stevenson's summary, made several years afterwards.* This upper portion, ending at 210 feet below the Buck Mountain, appears to be equivalent to the lower part of the Kanawha formation. The Campbell's Ledge flora, in the northern Anthracite field, only a few feet above the Shenango shale, or highest beds of the Mississippian, seems to be related to that of this upper or transition series, its place being near the Mercer horizon, a little way higher than given in Stevenson's Pottsville correlation, where it was placed at the horizon of the Sharon coal bed.

The relations of the Buck Mountain flora are considered in this paper. In all other publications referring to the Anthracite fields the Buck Mountain coal bed has been taken as the bottom of the Allegheny. This boundary, fixed arbitrarily by Professor H. D. Rogers, is convenient, as that coal bed is persistent and important in by far the greater part of the Southern and Middle fields. But Mr White has shown conclusively

* In a later paper, "Deposition of the Appalachian Pottsville," Mr White is inclined to see the Sharon coal horizon above the Gladesville sandstone, which would carry the upper limit of the Pottsville above the plane assigned by Stevenson. It is wholly probable that the stratigraphic evidence will confirm this conclusion, for the measurements on which Stevenson based his correlation of the Gladesville sandstone with the sandstone of Kentucky have been proved defective.

that this arbitrary boundary does not coincide with the paleontologic boundary, which is lower, 100 feet or more; he would include in the Allegheny a small coal bed, 72 feet below the Buck Mountain at Pottsville, and would carry the boundary downward to a still undetermined line between that coal bed and the plant horizon at 210 feet below the Buck Mountain. The flora of the Twin or Buck Mountain coal bed is comparable to that of the Clarion group in western Pennsylvania.

Table of Formations

Later information, as well as better knowledge of the relations obtained during the progress of this work, makes necessary some revision of the nomenclature employed.

No change is suggested for the Mississippian (A. Winchell, 1870) or Lower Carboniferous, and the terms, Logan, Tuscumbia, Maxville, and Shenango are retained; but paleontological studies, of which preliminary results have been published, seem to make clear that the writer has included under the Logan some deposits which may be of earlier age. The observations on which dependence was placed for connection around the northwestern and western outcrop in Pennsylvania and Ohio appear to be defective. There is apparently no room for doubt in the great part of the basin, for the vast number of oil-well records in southwestern Pennsylvania and in West Virginia make abundantly evident that the great oil-bearing sandstone is essentially continuous throughout and the same with that which both Andrews and Orton term Logan in southeastern Ohio.

But a new grouping for the Pennsylvanian or Upper Carboniferous seems to be required, in view of conditions described under the caption of Geographical changes. It is presented in the following table:

Pennsylvanian (H. S. Williams)	Pottsville (J. P. Lesley)	Rockcastle (A. R. Crandall)
		Beaver (J. P. Lesley)
	Athens (J. J. Stevenson)	Allegheny (H. D. Rogers, restricted by F. Platt)
		Conemaugh (F. Platt)
	Wheeling (J. J. Stevenson)	Monongahela (H. D. Rogers, restricted by I. C. White)
		Washington (J. J. Stevenson)
	Dunkard (I. C. White, restricted by J. J. Stevenson)	Greene (H. D. Rogers, restricted by J. J. Stevenson)

The term "Athens" refers to the county of that name in Ohio, and "Wheeling" to the stream which flows through the western portions of Greene and Washington counties of Pennsylvania, Marshall and Ohio counties of West Virginia, localities in which the respective columns are shown in their full extent.

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GALENA SERIES*

BY FREDERICK W. SARDESON

(Read before the Society December 29, 1906)

CONTENTS.

Extent

The so-called Trenton and Galena limestones of Wisconsin, Illinois, Iowa, and Minnesota have long been recognized as forming a practically continuous surface area, and they are so represented on geologic maps (figure 1). They are nearly coextensive with the subjacent Saint Peter sandstone. All three of these formations are greatly cut away by erosion on their northward side and they appear to have originally extended much farther than they now do in that direction. The extent of area from which these formations of the Ordovician age have been denuded is perhaps as great as their present surface area. This area was also once doubtless covered, in part at least, by the Maquoketa shales and by Silurian and Devonian formations. On the general southward side of the present surface area of the so-called Trenton and Galena limestones, these formations, with the overlying Maquoketa shales, extend with gentle dip very far, or an indefinite distance, under formations of the Silurian, of the Devonian, or of the Carboniferous, as the case may be.

Uniformity

The two formations under consideration here evidently had an originally very wide extent; and yet their combined thickness is perhaps never much over 300 feet, nor less than 200, where they are not eroded at the top. Their wide extent and their evident great uniformity of thickness are therefore such as to indicate a very widely uniform condition at the time of their deposition. The contained fossils show, of course, that

* Manuscript received by the Secretary of the Society December 29, 1907.

they are marine deposits. Some fossil species occur in practically every stratum from top to bottom of the series and in practically every locality

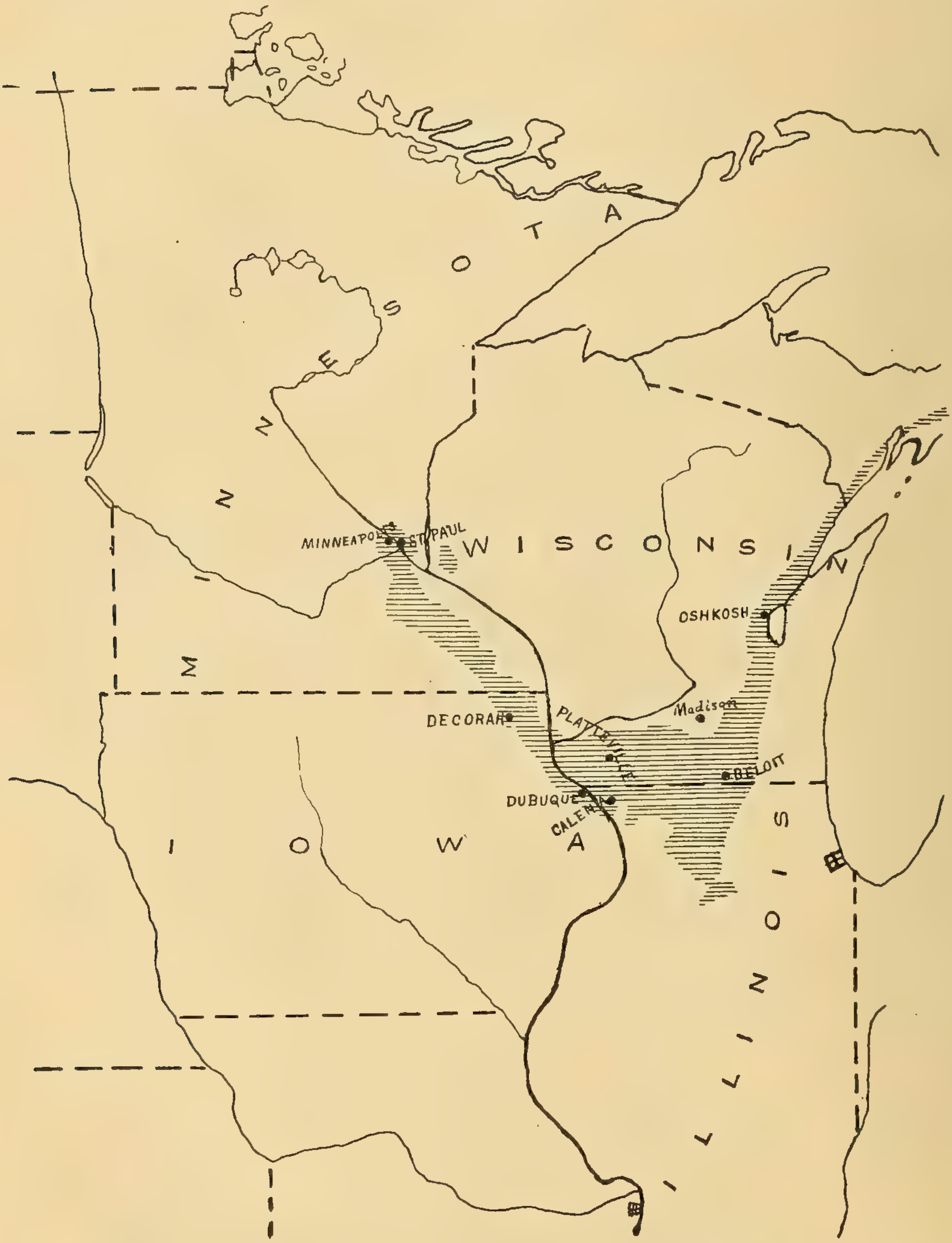

FIGURE 1.—*Map showing Distribution of the Galena and Trenton Formations.*

of the area, thus indicating a constantly uniform condition and a single marine province.

In regard to their lithologic characters, limestone dominates in both the Galena and Trenton, although diversity of rock is found in each, ranging from porous granular dolomite to lithographic limestone, clay-shale, and even fat clay in places No considerable sand constituent and no recognizable sandstone stratum occurs in any part, except just at the contact with the Saint Peter sandstone. Intraformational conglomerate* occurs in several zones from Minnesota to southwestern Wisconsin. This conglomerate appears to be the result of marine corrosion, and possibly erosion in part, and tends to prove that intervals of non-deposition of sediment obtained over part if not all of the area between certain periods of deposition. Again, there are carbonaceous bands of compacted fucoids which are in some places—for example, at Faribault, Minnesota—capable of being ignited and might be called a low-grade coal. These bands occur in diverse zones. Oolitic limonite occurs in places.

With such lithologic differences that in the region about Beloit, Wisconsin, the so-called Trenton is practically all limestone and the same about Rochester, Minnesota, practically all shale; that the Galena about the Beloit region has the typical granular dolomite or Galena phase, while south of Rochester the Galena phase is very limited, there is a notable contrast in the lithologic evidence as compared to that of the great uniformity of thickness and wide extent of the formations. The lithologic diversity may, in fact, lead a person to doubt that original uniformity existed or that these deposits were made under widely uniform conditions.

Whether the lithologic differences which we now see in the Galena and Trenton formations were largely original sedimentary differences or not can not be positively asserted at present. The petrographic changes which have taken place successively and in diverse parts of the so-called Trenton limestone and the Galena limestone have not been fully worked out. Discussions of their origin and special consideration of the ores and other minerals of these formations have, indeed, been repeatedly given,† yet much more on the whole remains to be traced out. For example, it is an observed fact that the originally silicious skeletons of sponges, as they occur at Minneapolis and in neighboring regions, are calcified, while in northern Illinois and southern Wisconsin many originally calcareous shells are silicified. Besides such mineral alteration, both exfiltration and infiltration, especially of calcium carbonate, have taken place locally to some extent. Possibly most of the differences be-

* F. W. Sardeson: Intraformational conglomerate of the Galena series, American Geologist, vol. xxii, 1898, p. 315.

† T. C. Chamberlin: Geology of Wisconsin, vol. i, 1883, pp. 151, 163, 169.

tween limestone and shale strata as we see them in the field are of such origin. In other words, where different kinds of deposit, such as calcareous and non-calcareous clay, were made originally, exfiltration of the former may have left both alike, or infiltration of the latter made a similar likeness, or even both such changes obtaining may have reversed the original difference.

While I have observed the variations of differences of rock in the two formations under consideration over the greater part of their extent, I am not prepared to make an exposition of petrographic changes which have taken place locally and successively in them. My observations have been directed chiefly along the line of the occurrence of fossils, their calcification, dolomitization, silicification, pyritization; of the occurrence of galenite and sphalerite in corals and shells; and of the exfiltration, compacting, and infiltration of fossils and fossiliferous strata. I am prepared only to express an opinion, on this partial evidence, that the diversity of rock type has been increased as a rule; that the original condition of these formations was more uniform than their present condition. I may add that the internal casts of shells in the clay beds are generally limestone still; also, as I have observed, the fossil shell of *Lingula iowensis,* Owen, proves local compacting of strata. The specimens of that species may occur in any stratum of the series. They are generally in vertical position. They show a shortening from vertical compression of the matrix of from one-tenth to nine-tenths of their original length.

Regarding paleontologic evidence, I have already aided in making known facts tending to prove that there was general uniformity of faunal conditions over the entire area from Green Bay, Wisconsin, to Dubuque, Iowa, and from Beloit, Wisconsin, to Minneapolis, Minnesota. Under direction of Professor C. W. Hall, I traveled over the entire area under consideration and published the results as to the faunal and stratigraphic succession in Minnesota* and gave some comparison of the same, with the stratigraphic succession as seen in Wisconsin. Nine or ten distinguishable faunal zones or beds are recognizable in Minnesota, and the same zones are evident over the entire area in Wisconsin, Illinois, and Iowa as far as the formations are accessible or preserved. Later, a more complete correlation was published,† and in this case special attention

* C. W. Hall and F. W. Sardeson: Paleozoic formations of southeastern Minnesota, Bull. Geol. Soc. Am., vol. 3, 1892, pp. 331-338; F. W. Sardeson: The range and distribution of the Lower Silurian fauna of Minnesota, with descriptions of some new species. Bull. Minn. Acad. Nat. Sci., vol. 3, 1892 (excerpt April 6).

† The Galena and Maquoketa series, American Geologist, vol. xviii, 1896, p. 356, and vol. xix, 1897, p. 21.

was paid to the application of names to the several parts of the Galena and also of the Maquoketa series. N. H. Winchell and E. O. Ulrich* at the same time adopted a very similar stratigraphic and paleontologic scale as my own for Minnesota, and they correlate not merely with Wisconsin, but adopt the formational names Stones River and Black River from more distant regions, instead of using the name Trenton limestone, this last name in turn being used instead of the term Galena limestone.

Without attempting to repeat to any extent the evidence as it appears in the cited articles concerning the two formations now under discussion, I may say in brief that the extent, uniformity of thickness, evident original petrographic equality, and, above all, the evidence of persisting or coextensive faunal zones, marked in particular by certain migrations of species over the entire province, show that practically the same strata extend over the area of the Galena–Trenton in the four states already named. It is further evident that when a geologist adds to the knowledge of these formations in one part of the area, that knowledge extends also to other parts, and that likewise the nomenclature of the formations requires uniformity for the entire area.

Nomenclature

In spite of the local petrographic diversity, the same two formational names of Trenton and Galena have been employed over the entire area in the several states. This continuance or seeming uniformity of nomenclature may of course have been aided largely by the Saint Peter sandstone's sharp contact under the "Trenton" and the contrast of the Maquoketa shales upon the Galena, whereby the stratigraphic equivalence appears doubly evident. That the aid of the contrasting lithologic characters of subjacent and superjacent formations has been relied on by authors is indicated when we find that in northern Iowa and southern Minnesota, where the overlying Maquoketa is rather a limestone than a clay formation, there the nomenclature has been least conformable in its application. In Alamakee county, Iowa,† the shaly bed at the top of the Galena was sometimes passed over or overlooked and the term Galena was applied to the Maquoketa limestone, since it looks like the Galena lithologically.

Again, in southern Minnesota a shaly bed really belonging to the Galena stratigraphically is called Maquoketa in official reports,‡ and the

* Geol. and Nat. Hist. Surv. Minn., Final Rept., vol. iii, 1896, pt. 2, p. lxxxiii.

† Iowa Geological Survey, vol. iv, 1895, p. 80.

‡ Vide Geol. and Nat. Hist. Survey of Minnesota, vol. iii, pt. I, p. 1. "Names used in the Minnesota Reports, 1872-1892."

calcareous Maquoketa equivalent formerly gave rise to the report that the Silurian–Niagara limestone extended into Minnesota, though it is really absent there, the Devonian lying with unconformity on the Ordovician.

By reference to faunal zones it can be shown also that the demarcation between the so-called Trenton and the Galena has been drawn by authors with great variance in differentt states and counties. The two formations, in short, had been recognized less uniformly over the entire area than the uniform employment of the names Trenton and Galena would imply. The extent of the variation appears in the scale and tabulated references in the article already cited* and need not be discussed further here.

The Beloit Formation

The name Trenton limestone was brought into use in Wisconsin by James Hall† in place of an older name, Blue limestone, on the theory that this formation is the equivalent of the Trenton limestone of New York. Hall also used at the same time the name Galena limestone for the galena or galenite-bearing strata above the Trenton, the town of Galena, Illinois, being presumably the type locality for this formation.

The use of such a mixed nomenclature, partly local in origin and partly from correlation with a distant, disconnected surface area, was never well designed to avoid confusion of terms. That the Galena itself is largely the equivalent of the New York Trenton limestone, while the so-called Trenton of Wisconsin is not, must be now admitted as evident.‡ To the problem which this mixed nomenclature presents either of two alternatives offered a solution: The one was to use local terms only; the other was to use exclusively exotic terms. I chose the former alternative in 1896,§ and accordingly proposed the name Beloit formation to replace the name Trenton in this region. According to the then outlined plan, the entire series of fourteen beds or faunal zones from the base of the so-called Trenton (Beloit formation) to the top of the Ordovician in this region divides into two series or groups the Galena and the Maquoketa. The Galena series divides into Beloit formation and Galena formation. Of the first nine faunal zones in ascending series the first five are comprised in the Beloit formation and the next four in the Galena formation. The tenth zone, that part of the limestone above the "cap rock"

* The Galena and Maquoketa series, American Geologist, vol. xviii, 1896, p. 356.

† Foster and Whitney's Report on the Geology of the Lake Superior Land District, 1851.

‡ N. W. Winchell: American Geologist, vol. xv, 1895, pp. 33-39; R. D. Irving: Geology of Wisconsin, vol. ii, 1877, p. 558.

§ American Geologist, vol. xviii, 1896, pp. 360-361.

at Dubuque, Iowa, is preferably joined to the Maquoketa series with four other faunal zones.

The reasons for choosing the name Beloit formation is obvious, the stratigraphic and faunal succession having been long well presented* from the locality of Beloit, Wisconsin. The line of demarcation at the top of the so-called Trenton—that is, the Beloit formation—had been well enforced there by Chamberlin. His use of the term Trenton was clearly the same as that employed in the "lead region" proper to the west. I had established by four successive trials or seasons' work that the five faunal and stratigraphic zones, as I had learned them at Minneapolis, namely, (1) the Minneapolis limestone (or Buff bed), (2) the Bellerophon bed, (3) the Stictoporella bed, (4) the Stictopora bed, and (5) the Fucoid bed, in ascending order, are the equivalents of the Buff limestone (1), Glass rock (2, 3), Brown rock (4), and Green rock (5) of the "lead region" of southwestern Wisconsin,† and of the Lower Buff (1), Lower Blue (2, 3), Upper Buff (4), and Upper Blue bed (5) of the so-called Trenton in the Beloit district. The term Beloit appeared to be well designed to replace the term Trenton, as it had been generally adhered to in Wisconsin for over forty years.

Regarding further the demarcation of Trenton and Galena, Lapham writes in 1851 of the Galena limestone:‡

> "It is a soft yellowish, magnesian limestone, very fully described in the report of the United States geologists for 1839, as well as by Mr. Hodge and others at an earlier day. It is usually identified in distant localities by the occurrence of a peculiar fossil coral, resembling the *Coscinopora sulcata* of Goldfuss, the tubes of which are sometimes filled with lead."

This lead coral, as it is called, is known to be *Receptaculites oweni*, Hall.

Again, James Hall, as early as 1847,§ described *Orthis subæquata*, Con., from the Blue limestone which he afterwards called Trenton, at Mineral Point, and this fossil appears to have never been referred by any author to the Galena. I have observed in the field that the demarcation of the Beloit formation from the Galena can be drawn between the zone of *Orthis subæquata*, Con., and that of *Receptaculites*. These fossils are common and easily observable, and the demarcation line is a very persistent one, none better occurring in the Galena series. Since this forma-

* T. C. Chamberlin: Geology of Wisconsin, vol. ii, 1877, p. 290.
† J. D. Whitney: Geology of Wisconsin, vol. 1, 1861, p. 253.
‡ J. W. Foster and J. D. Whitney: Geology of the Lake Superior Land District, pt. 2, p. 169.
§ Paleontology of New York, vol. 1, 1847, p. 118.

tion is nowhere entirely limestone and in places is more than half shale, the designation of it as limestone was changed by me to that of formation.

It should, of course, be expected that the term "Trenton," having been long employed, would be slow in dropping out of use, and also that confusion from conflicting usage of terminology might lead to the use simply of Galena series or group alone for most purposes of discussion, the terms lower, middle, and upper Galena falling into use where exact correlation is not made or is not practicable. For example, Galena lower limestone, Galena lower shales, Galena middle limestone appear to be sufficiently scientific terms for well logs and profile sections constructed from the same. For the solution of other special problems, such as the origin of lead and zinc—although the stratigraphic and paleontologic evidence at the strongly mineralized spots where the mines are developed is generally obscured—too exact and detailed correlation of the entire area can not be obtained and formational names would be required.

The Platteville Limestone

H. F. Bain, describing the Galena limestone in northwestern Illinois, refers to *Receptaculites oweni* as occurring 40 feet above the bottom of the formation.* This reference is further explained on the preceding page of his report when he says:

> "The Trenton in this area is about 40 feet thick. To the north a greater thickness has been assigned to it, but this is due not to a thickening of the strata, but to the reference of a portion of the overlying beds to this formation."

His Galena is thus evidently extended downward 40 feet, leaving only 40 feet, or just half, of the Trenton or Beloit formation in his Trenton limestone. Bain's language and action seemed to imply that others have been in error when they included more than 40 feet of strata in the Trenton.

This description of the "Trenton" by Bain is of special significance when taken in connection with a later report by him on the "Lead and zinc deposits of northwestern Illinois.† Here appears what might be meant by his expression "farther north." On page 21 of the Bulletin cited he says:

> "North of the mining district the lower portion of the Galena is not dolomitized and is lithologically similar to the underlying Platteville."

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* U. S. Geological Survey, Bull. no. 225, 1903, p. 205.

† H. F. Bain: U. S. Geological Survey Bull., no. 246, 1905, pp. 18-21.

Platteville is a new formational name which Bain is proposing for the so-called Trenton.

"Since the lithographic character has usually been relied on in discriminating the two, the line between them has been drawn at different horizons in various parts of the region, and from north to south crossed the stratigraphic horizons diagonally."

The introduction of a proposed new formational name gives still further significance to the work of that author on the Galena series. On page 18 appears the following words:

"*Platteville limestone.*—The beds included under this name have long been known in this district as the Trenton limestone. Since it is now believed that they are not the exact equivalents of the Trenton in its type locality, it is proposed to use a local name for them. The formation is typically exposed in the vicinity of Platteville, Wisconsin, and its entire thickness may be seen along Little Platte river west of that town. The beds are largely made up of non-magnesian limestone. In the lower portion are certain magnesian beds which are distinguished from the dolomites of the Galena by their earthy appearance. The Platteville limestone ordinarily has a total thickness of 60 feet while extremes in thickness run from 40 to nearly 75 feet."

He then gives a generalized section, which incidentally shows the Platteville in Illinois to be from 56 to 80 feet thick, as follows:

	Feet.
4. Thin beds of limestone and shale	10–20
3. Thin-bedded brittle limestone, breaking with conchoidal fracture	25–30
2. Buff to blue magnesian limestone, heavy bedded, frequently a dolomite	20–25
1. Shale, blue	1–5

Numbers 1 to 4 are then discussed in some detail, in general agreeing well with previous descriptions of the buff rock, glass rock, and at least part of the brown rock* already cited.

I am somewhat familiar with the "complete section" along the Little Platte river at Platteville and find some difficulty in believing that Bain is right in saying that the Galena lithologic phase is found in rock resting on top of the section above cited. I can remember also having had some difficulty with the stratigraphy there. On one side of a ravine by the roadside was the rock and index fossils of zone number 3 and a little way across the same ravine, at the same horizon, was quite the same brown rock with index fossils of zone number 5 in it. Except for the index fossils, I should have suspected no stratigraphic deception and concluded that the Galena rested on the lower bed (3), instead of bed

* J. D. Whitney: Geology of Wisconsin, vol. 1, 1866, p. 152.

number 5. The "complete section" at Platteville, as I saw it, extended in partial out-crops along the river for several miles.

U. S. Grant* describes the same section as Bain and adopts the name Platteville limestone. Calvin† appears to be ready to adopt the same in some sense, and the term Trenton is therefore evidently to give place to some local name. None of these authors who have employed the name Platteville limestone have made objection to or mentioned the Beloit formation. We are left to our own resources to discover the relation which the one may have to the other.

Reference to the section above mentioned makes it evident that the so-called Trenton as interpreted by Bain includes only the lower half of what Chamberlin‡ called Trenton in the south-central part of Wisconsin. In searching for the authority for Bain's interpretation I find that his description of the Galena limestone§ offers a clue to work on. He says:

> "It has long been known as the Galena limestone, a name applied by James Hall to the beds in and around Galena, Illinois, and above the socalled Trention."||

Hall describes the limestone at Platteville, at Galena, and at Dubuque. Of the Trenton he says¶ finally:

> "In all these localities the entire thickness of these lower limestones, which can clearly be identified with the Trenton and associated limestones of the east, is less than 50 feet; but it is possible that some better exposure would give a greater thickness."

One might be deceived in Hall's meaning here if he forgot the fact that Hall always quotes *Orthis subæquata,* Con., and associated fossils as typical Trenton species. *O. subæquata,* Con., proper belongs to the two zones, 4 and 5, which appear to lie above Bain's section of the Platteville limestone; and this limestone, which includes zones 1, 2, and 3, bear *O. perveta,* Con., instead of *subæquata* proper. Of the Galena, Hall says in the original description already cited (page 147):

> "The principal fossil resembles a *Coscinopora*, but is probably a *Receptaculites.*"

Briefly stated, Platteville limestone is obviously synonymous with Beloit formation as to the intention to displace the so-called Trenton. The term Platteville is not a "local name" in the sense of being applied

* U. S. Grant: Economic Geology, vol. 1, 1905-6, p. 234.
† S. Calvin: Journal of Geology, vol. xlv, 1906.
‡ Loc. cit.
§ Op. cit., p. 20.
|| Foster and Whitney: Geology of Lake Superior Land District, 1851, pt. 2, p. 146.
¶ Loc. cit.

to a single outcrop or within one county or state. The name Platteville has been introduced without reference to the already published and defined name Beloit formation. It is defined, as I think, without regard for the geologic conditions at its type locality. It is also based upon a wrong interpretation of the so-called Trenton and ignores the faunal distinction which earlier founders of the Galena and Trenton formations sought to establish.

The Platteville limestone appears to be designed to include the remnant of the series or group when the Galena limestone is extended downward to cover all the dolomitic or Galena phase of these rocks. It is evidently based on a lithologic distinction. The basing of the formational unit directly and indirectly on lithologic characters in the Galena series is worth further consideration.

The formational Unit

There seems to me to be a growing tendency, especially on the part of of the directing geologists, to base the distinction of formational units on lithologic rather than on faunal-floral evidence. The tendency in this direction in many instances seems so marked as to be called a policy. In case of the Galena series, the results of the two methods can be made to compare and to show how the use of lithologic evidence, as generally made, leads to confusion. While I am not disposed to blame the entire existing confusion to lithology, the necessary difficulty which arises from the lithologic formational unit seems worthy of full consideration.

In this connection attention should be paid also to the very recent article, "Notes on the geological section of Iowa," by Calvin,* in which the question of confusion in connection with the use of the terms "Trenton" and "Galena" are briefly discussed. After referring in this article to an earlier discussion† of the "confusion which has arisen" and "the probable causes of such confusion," he says finally:

> "Lithology and not stratigraphy was the basis of that classification. It is now proposed to use the term Galena for all the strata above the 'Green shales,' whether they are dolomitic, as at Dubuque, or are non-dolomitic, as along the river at and above Decorah" [Iowa].

Again:

> "Bain's name 'Platteville' is acceptable for the beds below the top of the 'Green shales.' "

While Calvin thus recognizes the erroneous way, he yet appears bound—by usage, perhaps—to follow it. While he appears to rebuke

* Samuel Calvin: The Journal of Geology, vol. xiv, 1906, p. 573.
† Samuel Calvin: Iowa Geological Survey, vol. x, 1900, p. 402.

the use of lithologic basis for formational units, yet he adheres to the old lithologic interpretation of the Galena as at Dubuque and proposes to use it as the basis for a new classification. The demarcation below the "Galena" is made the "Green shales"—a lithologic character—and Bain's Platteville limestone is to include the green shale. In reality this step which he now takes seems to be calculated to open the way for some one to give a new formational name to the "Green shales" as lithologically a formational unit, since the band of shale or "Green shales" as at Dubuque, Iowa, when followed up into southeastern Minnesota, becomes as great or even greater in thickness than is either the limestone below it or the Galena above it. As is easily shown from faunal evidence, its borders run diagonally both downward and upward (see fig. 2) in relation to the strata and faunal zone. Then, also, instead of forming a sharp demarcation at their boundaries, the shales graduate or alternate in strata with the limestone just as the limestone and the dolomite also irregularly graduate or alternate, rendering lithologic discrimination locally uncertain as it is also regionally unequal.

The logical result of basing formational names on lithology in the manner indicated is to give an irregularly variable scale rather than a constant one. In the Galena series it appears to have been impractical in the immediate past, tending more toward making the job last than to bringing scientific results, and it promises nothing better for the immediate future. It promises a practically different result for stratigraphic division in each district of the entire area of the Galena series' extent. With imminent double system of geological reports before us, with overlapping quadrangles and counties, an increase in the confusion must be anticipated.

As said before, I am not prepared to state fully, but find evidence to indicate that a very thorough lithologic interpretation or petrographic and stratigraphic study of the Galena series might tend to produce much the same conclusions regarding the formational units as have paleontologic studies; yet with the best application of lithologic method, namely, with such careful scientific interpretation as petrographic study might imply, it does not appear to me to promise a better basis for the determination of formational units than does the paleontologic evidence when each is taken in conjunction with stratigraphy.

Stratigraphic and paleontologic Classification

Since the entire surface area of the Galena series had been one or more times surveyed before my work on it began, there appeared to me to exist at that time a ready means for establishing a uniform strati-

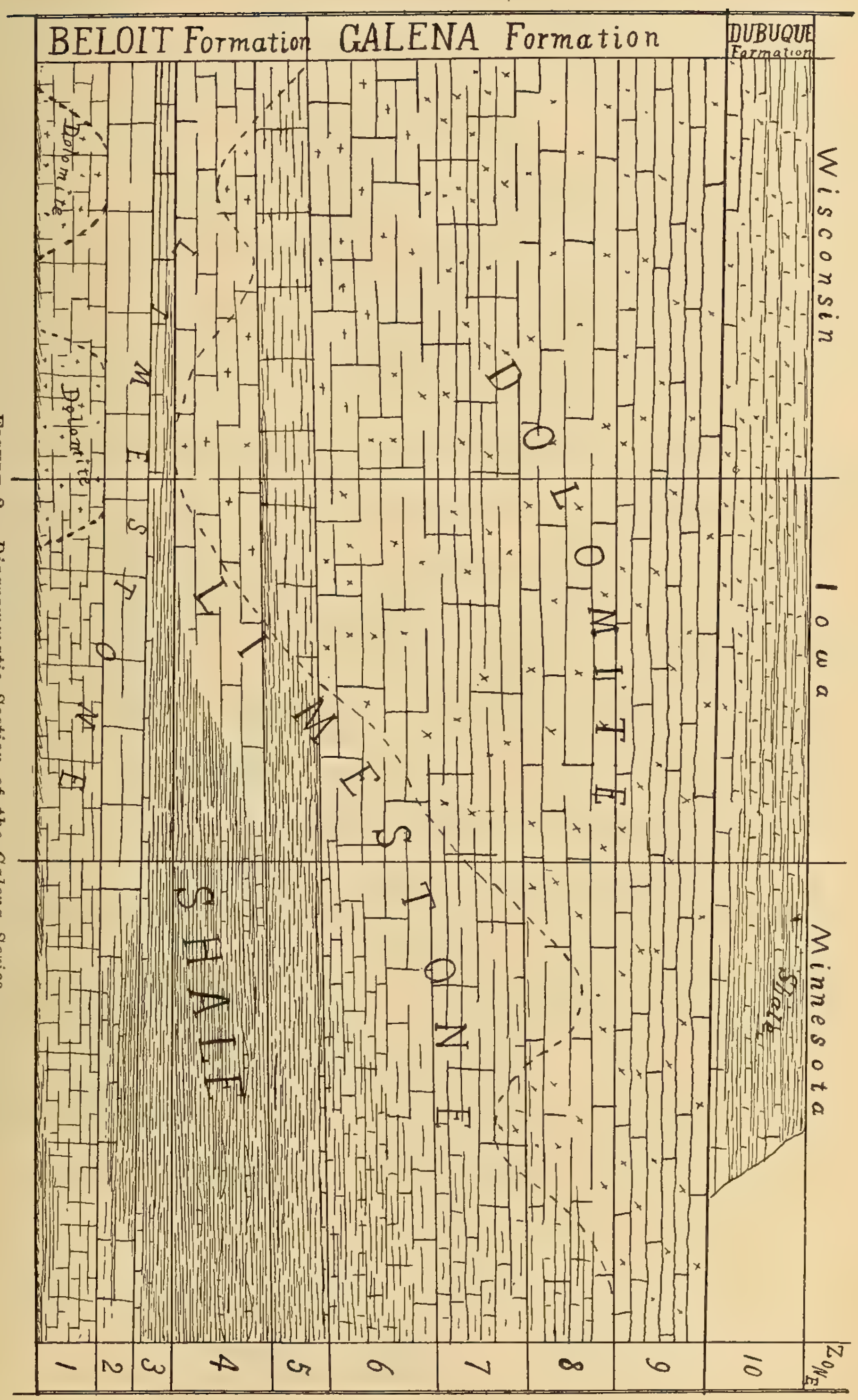

FIGURE 2.—*Diagrammatic Section of the Galena Series.*

Showing the gradation of the lithologic characters in Wisconsin (Illinois), Iowa, and Minnesota in relation to stratigraphy and to proposed formational boundaries.

graphic scale and equal formational division. By determining first of all the value of the units, which each author had recognized, these could then be compared in terms of a uniform stratigraphic-paleontologic scale. Besides the early reports of D. D. Owen, John Locke, J. G. Perceval, I. A. Lapham, James Hall, J. D. Whitney, and C. A. White, the descriptions by A. H. Worthen, H. C. Freeman, Frank H. Bradley, and James Shaw in Illinois, by T. C. Chamberlin, R. D. Irving, and Moses Strong in Wisconsin, by Chas. R. Keyes, W J McGee, Samuel Calvin, W. H. Norton, and others in Iowa, and by N. H. Winchell, C. W. Hall, E. O. Ulrich, and others in Minnesota, could be cited so as to set a standard for uniformity in practically every part of the field. In a former publication* I have offered such a comparison of the work of the authors named. Although this was set forth, necessarily, in brief form, it was hoped that it would serve to introduce a consistent use of formational units if perchance fellow-workers desired such to prevail.

The Maquoketa series was included with the Galena series in that effort, and in regard to the Maquoketa it may be noted that the calcareous beds are no longer called Niagara in Minnesota,† the absence of Silurian and the unconformability of the Devonian on the Ordovician being apparently recognized there and in northern Iowa.‡ In Fayette county, Iowa, also the calcareous Maquoketa beds are recognized as such and not called Galena,§ as the same had been in the near-by county. In regard to the Galena series, on the other hand, results are meager. Discussion and description of the Galena series have been put forth from the point of view of the lead and zinc region. The economic aspect of the subject due to lead and zinc deposits, which seems earlier to have rather hindered a careful correlation of strata between Beloit and Platteville, for example, appears now to ignore even that geologic correlation which has been put ready to hand. Since Van Hise‖ has recognized certain important relations between ore deposits and organic matter in strata in the Galena series, it may be essential that greater care in the marking of organic zones should follow. The formational boundaries should accordingly be established not by lithologic characters which may run obliquely across a particular organic zone, putting it into two such geologic formations, but by such characters as may place a particular zone in uniform relation to one formation in which it lies and to other such zones.

* American Geologist, vol. xviii, 1896, p. 356.
† Geological and Natural History Survey of Minnesota, vol. vi, 1901, preface plate.
‡ Op. cit., description to plate 10; and Iowa Geological Survey, vol. 13, 1901, p. 39.
§ Iowa Geological Survey, vol. 15, 1905, pp. 438 and 463.
‖ U. S. Geological Survey Monograph, vol. 47, 1904, p. 1157.

Notwithstanding the tendency or policy of establishing formational units on lithologic grounds, I wish to renew the suggestion that the Galena series, and the Maquoketa series as well, be divided into formations with stratigraphic and faunal definition. The term Beloit formation should extend as before described, including all the range of *Orthis subæquata,* Con. The top of this formation comprises the Fucoid bed, in which *Orthis lynx,* Eichw., and *Orthis pectinella,* Emmons, occur, the former ranging upward, the latter being limited to that zone. The top of this formation can be located by these easily found and recognized species. The Galena formation should include the Orthisina zone, in which are the first Receptaculites-bearing strata, and extend upward preferably to the top of the zone of *Maclurea cuneata,* Whitf.—that is, to the top of the "cap rock" at Dubuque, Iowa. The strata of irregular limestone and interlaminated carbonaceous shales, which extend at Dubuque, Iowa, from the "cap rock" to the blue shales of the Maquoketa proper, I should include in the Maquoketa series and should give to them the new name of *Dubuque formation.* This formation coincides with the Triplicia bed or zone as previously defined.* In like manner I should distinguish the Maquoketa formation proper from the upper beds, or Wykoff formation.

Since the preceding paragraphs were written and read before the Society, another Annual Report of the Iowa Geological Survey has appeared in print.† It includes the report on the Geology of Winneshiek county by Professor S. Calvin. In this report, the part of a synoptical table‡ presents the following classification:

<table>
<tr><th>Series</th><th>Stage</th><th>Formation</th></tr>
<tr><td rowspan="7">Trenton</td><td rowspan="4">Maquoketa</td><td>Brainard shale</td></tr>
<tr><td>Fort Atkinson limestone</td></tr>
<tr><td>Clermont shale</td></tr>
<tr><td>Elgin shaly limestone</td></tr>
<tr><td rowspan="3">Galena</td><td>Galena limestone</td></tr>
<tr><td>Decorah (Green) shale</td></tr>
<tr><td>Platteville limestone</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">Saint Peter</td><td>Glenwood shale</td></tr>
<tr><td>Saint Peter sandstone</td></tr>
</table>

* Loc. cit., vol. 19, pp. 21 to 24.

†Iowa Geological Survey, Annual Report, vol. 16.

‡Loc. cit., p. 60.

The new name Decorah shale is of interest here. Of this he says:

"The persistent body of shale between the two parts of what has generally been called the Trenton limestone is named Decorah shale, from the city in which it is typically developed. Heretofore it has been recognized as a distinct geological unit under the name 'Green shales,' . . . ."[*]

On page 85 of this report, figure 7 represents a photograph of "a very typical exposure" of the Decorah shale, with overlying basal ledges of the Galena limestone at Decorah, Iowa. This exposure in "the Dugway," shown in figure 7, is a familiar one to me, and I can therefore at once concur in designating as Galena the strata seen in the little old quarry at the top of this exposure. Moreover, the "Decorah shale" as here shown is the Upper Blue bed (Fucoid bed) which is the top of the Beloit formation or "Trenton." This being the case, the term Platteville *stage,* which Calvin has employed in the synoptical table, cited above, is synonymous with the term Beloit formation, and not with the Platteville as defined by Bain.

The "undisturbed Decorah shale" which is represented as the base of this shale in figure 6, page 83, *loc. cit.,* I do not recognize, but from the general description which is given in the report, it is evident to me that Calvin here includes in the Decorah shale the strata which I had included in both the Fucoid bed (5) and the Stictopora bed (4). The Stictoporella bed (3), which includes the lowest strata in which *Plectambonites sericea* Sowerby is known to occur, he evidently places in the "Platteville *limestone.*" The term Platteville limestone, as used[†] here by Professor Calvin, appears therefore to be the exact equivalent of Bain's section of the Platteville at the type locality. This being true, the horizon of the "green shales" in the "Platteville" of Wisconsin is included in the "Platteville limestone" at Decorah, Iowa, and not in the "Decorah (Green) shales."

The following table represents the formational divisions which still appear to accord most nearly with historical and geologic conditions, in relation to the Galena stage:

Series	Stage	Formation	Zones
Trenton	Maquoketa		11–14
		Dubuque formation	10
	Galena	Galena formation	6–9
		Beloit formation	1–5
	Saint Peter	Saint Peter sandstone	

*Loc. cit., p. 61.
†Op. cit., pp. 60, 76, 80-84.


Frenchtown
Pittstown
Byram
Lambertville
Stockton
Flemington
Round Mt.
CUSHETUNK MT.
S.B.
Ringoes
SOURLAND MOUNTAIN
Hopewell
Pennington
ROCKY HILL
Princeton
TRENTON

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BY J. VOLNEY LEWIS

(Presented by title before the Society December 29, 1906)

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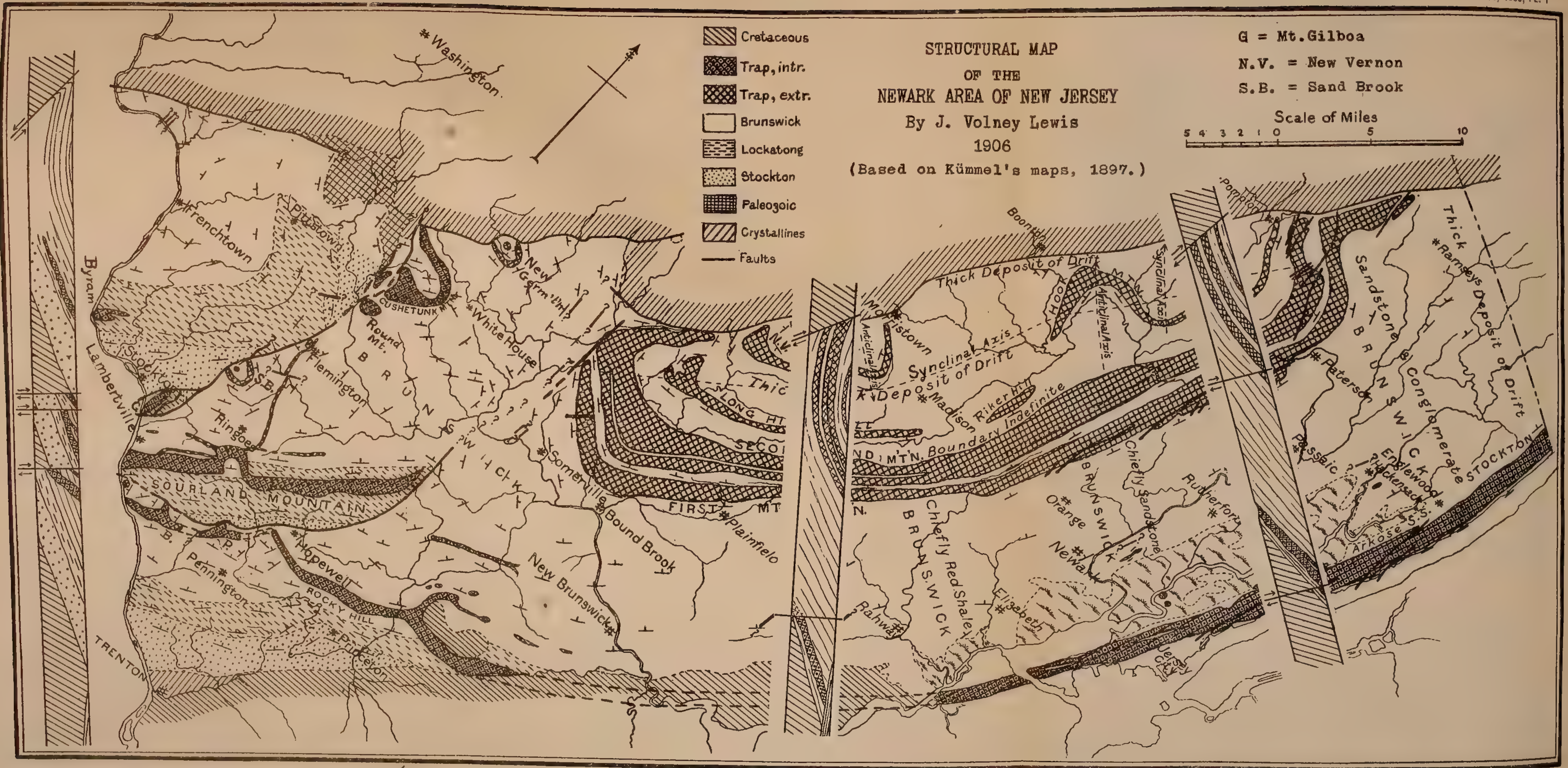
SUMMARY

In addition to the structures and relations heretofore recognized, the following conclusions are presented in this paper:

(1) That the trap of Second Watchung mountain is a double flow, separated locally by sediments deposited on a warped surface.

* Published by permission of the State Geologist of New Jersey. Manuscript received by the Secretary of the Society March 8, 1907.



STRUCTURAL MAP OF THE NEWARK AREA OF NEW JERSEY

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(2) That there was further local depression, with corresponding thickening of sediments, in the interval between the Second Mountain flows and that of Long hill.

(3) The crescentic trap ridge of New Vernon is definitely correlated with that of Long hill.

(4) The small extrusive remnants at Sand Brook and New Germantown are regarded as probably identical, or at least contemporaneous, with the First and Second Mountain sheets.

(5) The hypothesis of a feeding dike along the western flank of the Palisades is regarded as highly improbable.

(6) The continuity of the Palisades sill with the Rocky Hill trap, suggested by several former observers, is practically established by data from deep wells and dredging operations.

(7) The further extension of the same sill to include Pennington and Baldpate mountains, Sourland mountain, mount Gilboa, and the Byram mass is regarded as almost equally certain.

(8) Numerous dikes and other small masses are regarded as offshoots of the Palisades sill.

(9) The intrusives are regarded as of later origin than the extrusives and earlier than the deformation of strata by faulting and tilting.

Introduction

AREA OF THE NEWARK SYSTEM

Of the long sinuous belt of Newark rocks extending from southern New York across New Jersey, Pennsylvania, Maryland, and into northern Virginia, perhaps a little more than one-fourth lies within the state of New Jersey (see map, plate 1). It occupies about one-sixth of the total area of the state in the form of a tapering belt from the Delaware river above Trenton northeastward to the Hudson river and the New York state boundary. On the Delaware it is 32 miles wide, and it narrows to about 16 miles across where it passes into southern New York, including wholly or in part the counties of Hunterdon, Mercer, Somerset, Middlesex, Union, Morris, Essex, Hudson, Passaic, and Bergen.

TOPOGRAPHY

The Newark area comprises a Piedmont plain which is intermediate in elevation and surface characters between the low, smooth Coastal plain to the southeast and the higher and more mountainous Highlands on the northwest. Along the northwestern border it is distinctly lower than the adjoining Highlands except west of Flemington, where the elevation of Hunterdon plateau approaches that of Musconetcong mountain. Along the southeastern margin it gradually passes into the low Coastal plain.

As a whole the area has an undulating surface sloping gradually to the southeast, but this is interrupted by conspicuous ridges, including the Watchung or Orange mountains and the Palisades ridge along the Hudson. Southwest of the Watchungs notable elevations occur in Cushetunk and Round mountains, Rocky hill, and the broad, plateau-like Sourland mountain. The greatest elevations are 839 feet on Cushetunk mountain south of Lebanon and 900 feet on Barren ridge, a somewhat disconnected part of the Hunterdon plateau south of Pattenburg.

Barring the conspicuous elevations enumerated above, the plain lies chiefly below 300 feet along the northwestern border, while much of the southeastern border is little above 100 feet.

Less pronounced but very important irregularities are produced in the surface by the prominent river valleys that have been worn down below the general level. Most notable of these is the Raritan, which has reduced large areas above New Brunswick to an elevation of less than 50 feet above tide. The same is also true of the Hackensack valley just west of the Palisades; but this valley is traversed by longitudinal ridges of hard sandstone, while its southwestern part has been depressed below the level of Newark bay and the adjoining meadows. The Delaware river, on the other hand, crosses the Newark area in a narrow trench bordered by bluffs that rise in places from 200 to nearly 500 feet high. In these parts of the valley precipitous cliffs often rise conspicuously on either side of the gorge, and the valley nowhere attains any considerable width.

CHARACTERS OF THE SEDIMENTARY ROCKS

The most characteristic sedimentary rocks in the New Jersey Newark are fine grained red shales; but there are also some sandstones and conglomerates and, at some horizons, thick massive argillites. Coarse conglomerates occur not only near the base of the series, but also near the top and at various intermediate horizons. Heavy bedded sandstones also occur at various levels, but more abundantly in the lower part. With the black argillites are some layers of gray and green flagstones and occasional thin layers of very calcareous shale, and in the red shales local variations to purple, green, yellow, and black occur.*

STRUCTURES OF THE NEWARK

Dip and strike.—The prevailing northeast-southwest trend of the ridges, whether of sedimentary or igneous rocks, is due to the tilting of the strata toward the northwest in a gentle monocline. This general statement is subject to various local exceptions and irregularities, how-

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* The origin of the Newark sediments is discussed by the writer in the Annual Report of the State Geologist of New Jersey for 1906.

ever, as shown on the map, plate 1. The departures from the prevailing northeast strike and northwest dip are due in varying degree to both folding and faulting. Smaller disturbances are produced locally by igneous intrusions, but by comparison these are insignificant.

It will be noted that in the southeastern half of the area, southeast of the Sourland and Watchung Mountain escarpments, the structure is remarkably simple and regular, with prevailing northwest dips of 10 to 15 degrees. From this line there is increasing complexity northwestward to where the Newark strata abut against the crystallines of the Highlands. Near the Delaware river, about Lambertville and Stockton, the structures are extremely involved and many details have not been satisfactorily deciphered. To a less extent this is also true of other portions of the northwest.

The remarkable uniformity of the red shales over most of the area constitutes the chief obstacle to an understanding of the structural relations. Folds and faults in these rocks are scarcely recognizable except where trap sheets are encountered, unless exposed in cuts and the deeper stream channels. In a region of low relief such sections are seldom found.

Folds.—The recurved, hook-like extremities of the Watchung mountains are due to a shallow, boat-shaped synclinal fold, the western side of which has been cut off by a fault along the border of the crystallines. Lying directly across the axis of this syncline and dividing it into three nearly equal parts are two smaller anticlines. The axis of one of these, the New Vernon anticline, lies two miles southwest of Morristown and Madison and passes through Green Village, near New Vernon. It pitches southeastward, like the end of an inverted boat, to the east of Green Village. The other, the Hook Mountain anticline, pitches in the opposite direction, the axis passing through Towaco and about 2 miles northeast of Boonton. The outcrops of the uppermost extrusive trap sheet have been thrown into two strong crescentic curves in opposite directions by these folds, and that about New Vernon is the only part of the western border of any of these sheets that escaped being sheared off by the great boundary fault through Morristown and Boonton that cut away the northwestern side of the larger syncline.

The spoon-shaped end of a large syncline lies west of Flemington, with its westward pitching axis passing through Frenchtown and the central part of the Hunterdon plateau. Similar but much smaller structures determine the small crescents of trap rock at Sand brook and New Germantown. There are also numerous small, wave-like undulations of the strata between the Watchung mountains and the Delaware river, as shown by frequent reversals of dip in this region, but the homogeneous character of the red shales has made it impossible to decipher the exact structure.

Faults.—Kümmel* has described the great Hopewell and Flemington faults, each of which has displaced the strata in the southwest many thousand feet, and also the three faults that determine the greater part of the northwestern boundary of the Newark. Besides these it is known that numerous small faults affect the strata, but these can seldom be recognized except where the actual fissure or shear zone can be observed in fresh exposures. When, however, a layer of distinct individuality, like a trap sheet, is affected by a fault of any consequence, this fact is often readily detected by the effects on the outcrop.

Wherever the trap rocks are freshly exposed in cuts and quarries certain prominent north-south or northeast-southwest fissures are nearly always found, and the crushed and slickensided materials between their walls, varying from an inch or less to many feet in thickness, give unmistakable evidence of displacement. In the majority of cases doubtless the actual movement along these fissures has been small, and perhaps the slight warping produced by the upheaval and tilting of these rocks would be sufficient to account for many of them; but from these slight displacements to faults involving a throw of several hundred feet there is every gradation. Many of the small irregularities of outcrop, particularly those sudden angular offsets in the trap sheets, have long been ascribed to faulting, and doubtless many others have had a similar origin.

Almost without exception the known faults of the Newark in this region have the downthrow on the east side of the fissure; hence the great Hopewell and Flemington faults of the southwest have caused a threefold repetition of a large part of the thickness of the Newark strata and their included trap sheets, and at least half of the width of the Newark belt along the Delaware river is due to this repetition. No such great faults are known in the central and northeastern parts of the belt, but displacements ranging from less than a foot to several hundred feet are of frequent occurrence in the trap sheets of the Palisades and the Watchung mountains, and similar faults are occasionally observed in fresh exposures of the sediments. It is altogether probable that the intervening areas are as greatly affected as the trap outcrops, and hence that no inconsiderable fraction of the width in the central and northeastern portions of the area is also due to repetition on a small scale by numerous faults.

The Trap Rocks

MODES OF OCCURRENCE

The Newark area of New Jersey is dotted and striped almost everywhere with outcrops of the hard, dark colored rocks usually known as

* Annual Report of the State Geologist of New Jersey for 1896, p. 78; 1897, p. 107.

trap or diabase. Both extrusive and intrusive types are abundantly represented—the former usually in the form of sheets that spread quietly over the surface, with only occasional local beds of tuff; the latter as sills, bosses, and dikes. Davis, Darton, and Kümmel have quite clearly differentiated the extrusive sheets from the sills.

The distribution of these rocks is shown on the map, plate 1. They are irregularly distributed over all parts of the belt and constitute more than one-tenth of the total Newark area of the state. Their prevailing northeast and southwest direction is notable. This is due to the preponderance of sheets, both extrusive and intrusive, and to their general conformity to the structure of the inclosing shales and sandstones.

RELATIONS OF THE EXTRUSIVE TRAPS

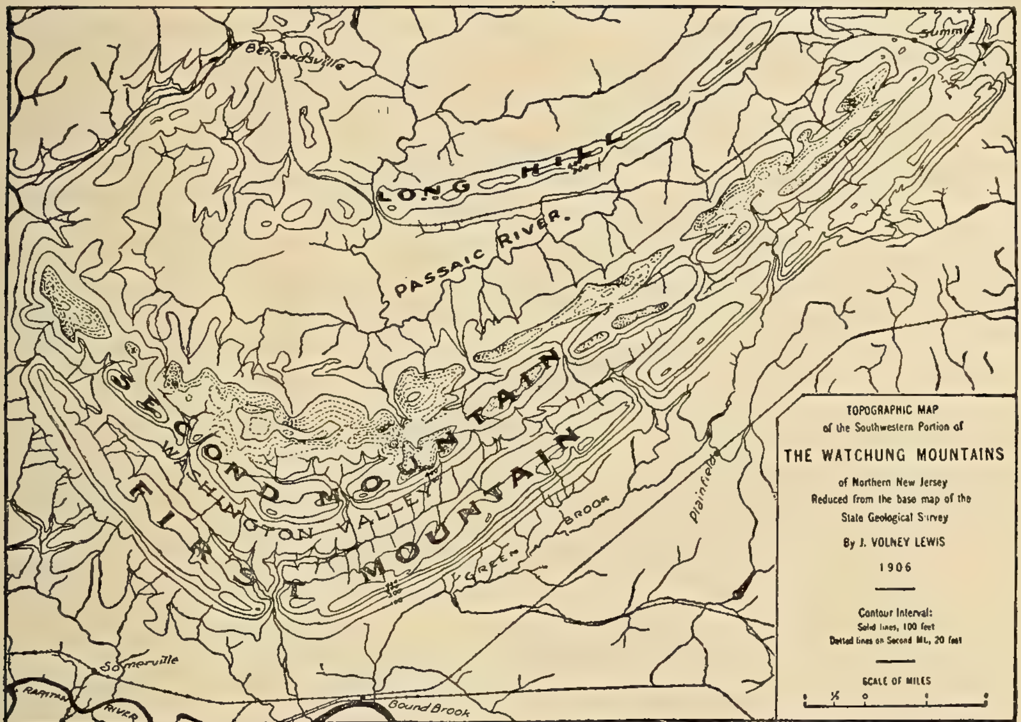
General characteristics.—The Watchung mountains, including the various trap ridges of three successive lava flows, are all extrusive, as are also the semicircular ridges near New Germantown and Sand brook. The grouping of these sheets in the west central portion of the area, where no intrusives occur, and their almost total absence from the areas of intrusives to the northeast and southwest are characteristics that are clearly shown by the map, plate 1. The former is the area of uppermost, and therefore of latest, Newark strata, while the deep-seated intrusive masses have been laid bare only where these later strata have been removed to great depths by erosion.

First mountain.—The narrowing down of First mountain north of Somerville and its final termination near Pluckamin seem to be due to the thinning out of the lowest extrusive lava sheet. Although no evidence of faulting could be detected in the homogeneous red shale of this region, Kümmel* suggests that this ridge might have been sheared off diagonally by an extension or a branch of the Hopewell fault, which may be continued in the deep gorge of the North branch of the Raritan.

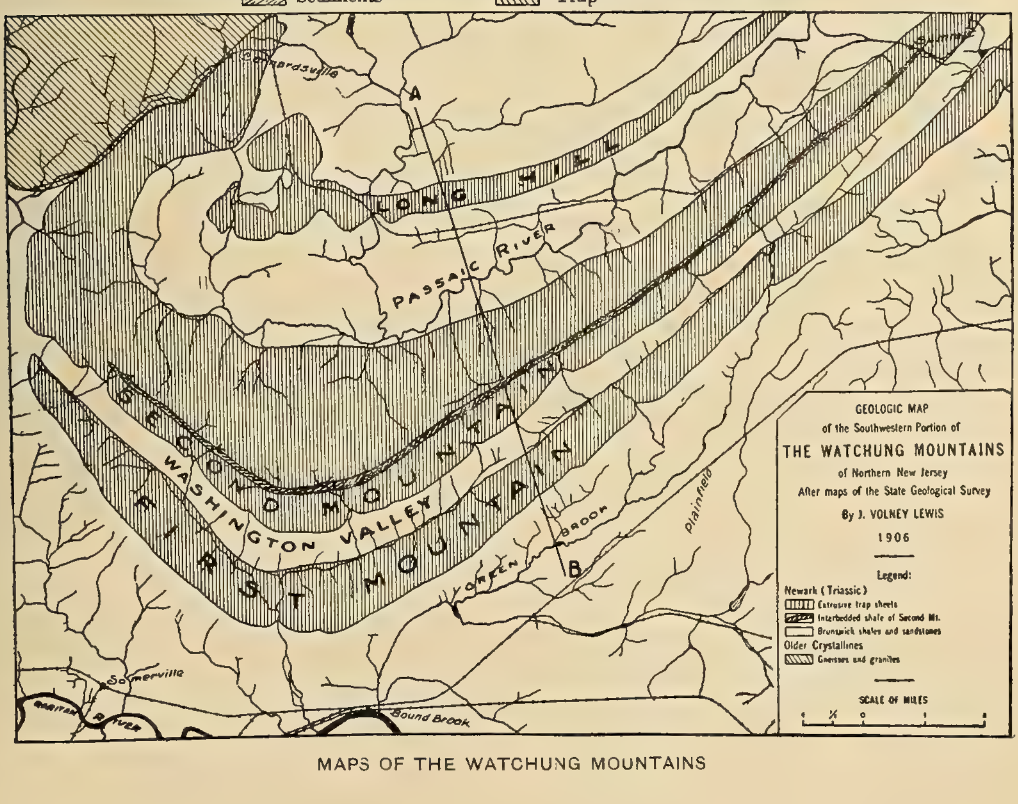
The double flow of Second mountain.—Second mountain recurves in hook form at its southwestern extremity until cut diagonally across by the great boundary fault near Bernardsville. This fault continues northward and terminates the curved extremities of all three of the extrusive sheets beyond Pompton.

The width of outcrop of the trap sheet of Second mountain varies greatly, the hook-shaped southwestern portion being much the broadest part (see maps, plate 2). Here also for a distance of 17 miles the crest is distinctly double, and in the intervening valley shale has been found at a number of places, either in wells or at the surface. The crest is single, however, at both ends of the ridge, and the gorge of Passaic

* Annual Report of the State Geologist of New Jersey for 1896, p. 81.



DOUBLE CREST OF SECOND WATCHUNG MOUNTAIN



MAPS OF THE WATCHUNG MOUNTAINS

river at Little Falls shows no shale in the trap. A well in Caldwell passed through 775 feet of trap without encountering shale; but a well near East Livingston, 3 miles southwest of Caldwell, gave the following section:*

	Feet
Soil	5
Trap rock	90
Brown sandstone	51
Trap rock	381
Total	527

Over the country between the two crests Darton found red shale fragments that he regarded as portions of underlying sediments.

Kümmel† considered the hypothesis of two successive flows of lava separated by an interbedded layer of sediment, but rejected it because the ridge is single and shows no included sediments at the extremities and at the gorge at Little Falls. Under the seeming necessity of choosing between this hypothesis and that of a curved longitudinal fault conformable with the present outcrop of the trap around the sharply recurved southwestern extremity of Second mountain, both Kümmel and Darton‡ accepted the latter, although no direct evidence of faulting was found.

The indirect evidence derived from a study of the width of outcrop and apparent thickness along different section lines may be summarized as follows: On the assumption (1) that there was no deformation in the intervals between the lava flows of the Watchung mountains (nor accompanying them); (2) that sedimentation was uniform throughout the area; (3) that the lava sheets are approximately of uniform thickness; their bases must have been originally parallel. Allowing for known faults, this is still true of First and Second mountains; but from the base of Second mountain to that of Long hill is a distance that varies greatly in different sections, and the apparent differences are greater where the double crests of Second mountain are most marked. This variation is ascribed to faulting, which Darton further assumed to be confined to the areas of the present trap outcrop. As Kümmel has pointed out, any or all of these various assumptions may be incorrect, and there is no reason for supposing that faulting has been restricted to the areas of the present trap surfaces.

The above hypothesis has been discussed elsewhere by the writer,§ and

* Kümmel: Annual Report of the State Geologist of New Jersey for 1897, p. 126.

† Loc. cit., p. 125.

‡ Bull. U. S. Geol. Survey, no. 67, p. 22.

§ The double crest of Second Watchung mountain, Journal of Geology, vol. xv, pp. 39-45.

the alternative hypothesis of a double flow with intercurrent deposition and warping proposed. This is practically the interbedded shale hypothesis referred to above without the restrictions of stability of land surface and uniformity of deposition between the lava flows, and in this form it is believed to be entirely consistent with all ascertainable facts and to involve no improbable assumptions. After the outflow of the first trap sheet of Second mountain, which averaged probably 500 feet in thickness, there began a gradual depression of what is now the southern axial region of the great Passaic basin (or Watchung mountain) syncline, the region northeast of Somerville and Bound Brook. Subsequent deposits were concentrated in this region, tending to build it up to the level of adjacent areas; but before this condition was finally attained another eruption occurred, forming a lava sheet of very variable thickness. Over the 50 feet or so of shales in the area of subsidence the maximum thickness of lava was at least 800 feet, while in the adjoining regions, where it overspread the bare flanks of the preceding flow, it probably did not exceed 200 feet in thickness. Thus the two flows, separated by a brief interval of deposition, merged into one on the sides of the incipient syncline, but in the trough of the depression were separated by a thin stratum of shale (see maps and sections, plate 2).

The sediments between Second mountain and the overlying trap sheet of Long hill give evidence of continued subsidence in the same region. There is a decrease of one-fourth in the thickness of the intervening shales at Madison as compared with those at Millington, and a much more rapid thinning out toward the west. The trap sheet of Long hill is also thicker about Millington, but, considering the thin and discontinuous character of this sheet, the variation in thickness may be due to other causes than the warped surface over which it flowed.

Third mountain, or Long hill.—Long and Riker hills and Packanack and Hook mountains, from their structure and attitude with reference to each other, are regarded as probably outcrops of a single extrusive sheet. There is no question as to their extrusive character, and they are all much thinner than the great flows that constitute First and Second mountains. Their disconnected character may be due to projecting lobes or tongues of a relatively slight flow of lava, or they may be the result of several small eruptions from independent vents. On the other hand, they may be regarded as the effects of glacial or preglacial erosion whereby the continuous sheet of lava was deeply notched, the portions that were most worn down being now buried by the thick glacial drift and alluvial deposits of the Passaic river that cover so much of this region. So far as known, all of these hypotheses seem to be consistent

with the facts; but, on the whole, one of the hypotheses of scant eruption seems most probable.

The New Vernon trap.—The trap crescent near New Vernon is a thin extrusive sheet exactly similar to that of Long hill, and the structure of the shales shows that it has been brought up by a dome-like anticline, or quaquaversal. Darton* thought it might be continuous with either the second or third Watchung sheets (Second mountain or Long hill) or an independent local extrusion. Kümmel† regarded it as either the western border of the third Watchung flow or an independent sheet. The structure of the intervening shales, however, makes it quite probable that the New Vernon trap is continuous with the third Watchung (or Long hill) extrusive, or at least contemporaneous with this, and therefore occupying the same horizon. The outcrop was thrown so far eastward by the anticline that it escaped being cut off by the great boundary fault along the adjacent border of the crystalline Highlands (cross-section, plate 1).

Sand Brook and New Germantown traps.—These two small remnants of extrusives have been preserved by spoon-shaped synclines with westward pitching axes, and in both cases they have been cut off to the westward by faults. Each contains remnants of two separate masses of trap, and the forms and relations seem to be exactly the same in both. The larger mass in each outcrops in a westward pointing crescent and curves downward beneath the shales within; the smaller caps a rounded hill between the points of the crescent, thus resting on the sediments overlying the synclinal sheet below. At New Germantown this upper fragment is separated, probably by erosion, into two small, disconnected masses.

Kümmel,‡ finding the contacts of these smaller masses so obscured by soil covering at both localities that their relations to the sediments could not be directly observed, was uncertain as to their extrusive character; but from their structure, lithic character, and the absence of metamorphic effects on the sediments, there can be little doubt of it.

Here, then, in each case are remnants of two lava flows separated by several hundred feet of shales, and both Darton§ and Kümmel† have shown that they occupy approximately the same horizons as the Watchung extrusives. The former, however, makes no reference to this point in the discussion, and the latter concludes that "there is no evidence that they are parts of the same flows." On the other hand, it may be shown that such a correlation is not at all improbable. The present Watchung sheets

* Bull. U. S. Geological Survey, no. 67, 1890, p. 34.
† Annual Report of the State Geologist of New Jersey for 1897, p. 91.
‡ Loc. cit., pp. 91, 92.
§ Bull. U. S. Geological Survey, no. 67, 1890, fig. 11, p. 35.

are certainly only remnants of the original flows, although still occupying a region some 12 by 40 miles in extent. If extended half as far again, they would spread beyond the most distant remnants at Sand Brook. Considering the thickness of the first and second Watchung extrusives at their southern extremities, it is not unreasonable to assume such an extension at the time of their origin.

If thus extended and of earlier origin than the Sand Brook and New Germantown traps, their outcropping edges would now appear in larger curves to the east of these. If, on the other hand, the Sand Brook and New Germantown traps were older than the Watchung sheets, we should expect them to appear in the shales beneath and southwest of the latter, unless they are parts of very limited local flows. This applies with particular force to the New Germantown trap, which is only six miles distant from the Watchung mountains. There is still another possible condition, namely, that neither the small synclinal remnants, on the one hand, nor the Watchung flows, on the other, have ever extended far enough beyond their present boundaries to overlap the regions now occupied by the other. In this case their relations can be established only by the stratigraphy, and it is impossible in the homogeneous red shales of this region to attain more than an approximate correlation. Even regarding the small areas as independent local flows, however, it is more probable, *a priori*, that the smaller eruptions were contemporaneous with the larger volcanic activity of the adjacent area, especially since the structure shows that they are at least approximately contemporaneous.

RELATIONS OF THE INTRUSIVE TRAPS

General characteristics.—The intrusives include the Palisades in the northeast and the entire assemblage of trap outcrops in the southwest except the small extrusive remnants at Sand Brook. Most of these are in the form of sills, or intrusive sheets, with smaller masses appearing as rounded bosses, as the Snake hills and mount Gilboa, or as thin dikes in many localities.

The Palisades sill.—There has been a wide acceptance among geologists of the "dike-and-sheet" structure of the Palisades trap, as depicted by Darton,* in which the lava is regarded as having been intruded "from a dike which follows at or near the western flank of the outcrop." Darton states that this structure is best exposed in the railroad tunnels across the ridge at Weehawken and near Haverstraw. The "dike-and-sheet" interpretation is thus undoubtedly due to the preponderating influence of these fine exposures where the trap does break upward across

* Loc. cit., p. 37.

the strata for several feet. These sections have been described in detail and illustrated in the reports, while the numerous conformable contacts have very naturally been passed over with a simple statement of the facts.

Kümmel* has described four conformable upper contacts, two unconformable, and two doubtful, while of the under contacts along the Hudson river only three are conformable, fifteen are unconformable, and one is doubtful. Yet, in spite of the numerous irregularities of the under surface of the trap and its constant shifting from one horizon to another, it is evident that in a broad, general view it is approximately conformable to the sedimentary strata. Even less irregularity is known in its upper surface, but probably if an equal number of contacts could be observed the conditions would be found about the same. At any rate, there seems to be no good reason why these upper contacts should be regarded as indicating the fissure arising from the deep-seated origin of the lava when it is evident that similar contacts beneath the palisades, where the lava sometimes breaks across more than a hundred feet of the strata, are in no wise susceptible of such interpretation. It is therefore contended that there is no evidence whatever to show that the Palisades sill is any less conformable to the inclosing strata westward down the dip than in its exposure along the strike. Of course, it must have come up through a fissure or other vent somewhere, but it would be a remarkable coincidence if this fissure should happen to follow the western flank of the present outcrop from Weehawken to Haverstraw (see cross-sections, plate 1).

Extension of the Palisades sill.—Various workers in this region have pointed out the probability that the Palisades sill is continuous with that of Rocky hill. Darton† states that "the interval between the Staten Island outcrops and those at Lawrence brook is mostly covered by Cretaceous clays, under which the Newark is known to extend for some distance, and it is possible that the trap continues southward and is similarly overlapped." The accumulation of data from deep well borings in the sixteen years since this was written now makes it practically certain that this supposition is true.

As pointed out by Darton, the shallow wells on Staten island show the continuation of the trap southward to the vicinity of Fresh Kills, opposite Carteret, New Jersey. Three wells at the car works at Carteret, after passing through sand and clay 60 feet and 90 feet respectively, struck hard rock that "dulled the drill in 15 minutes," and was reported by the contractor as "evidently trap rock." At Boynton Beach, three miles southwestward, the following well section was found:

* Annual Report of the State Geologist of New Jersey for 1897, pp. 62-72.
† Bull. U. S. Geological Survey, no. 67, 1890, p. 39.

	Feet
Clay, sand, and gravel	75
Red shale	3
Trap rock	70
Red sandstone	2
Trap rock	7
Total	157

Evidently a sandstone inclusion in the trap was here encountered. Two wells bored at Maurer, 2 miles north of Perth Amboy, found trap under 64 and 78 feet respectively of sand and clay. In a well a mile and a quarter south of Woodbridge hard rock was found at a depth of 63 feet. At first this was supposed to be trap, but afterward it proved to be indurated shale and sandstone, and is doubtless the metamorphic sediment overlying the trap.

At Keasby, on the Raritan river 2 miles west of Perth Amboy, hard rock, probably trap, was encountered under 72 feet of sand and clay. In dredging and blasting operations in the Raritan river a mile below Martin's dock a reef of indurated shale 500 feet wide was found crossing the river in a northeast-southwest course, 5 to 12 feet below low water. No trap rock was found, but it cannot be doubted that this corresponds to the belt of "baked" shales everywhere skirting the intrusive sills.

Again, 2 miles southeast of Deans, near Fresh Ponds, a bored well encountered trap rock under 60 feet of clay, unquestionably the buried margin of the Rocky Hill mass which outcrops abundantly about Deans.*

The several dikes east, south, and west of New Brunswick bear the same relation to this covered extension of the sill as do those of Arlington, Snake hills, Granton, and Bogota to its prominent outcrop in the Palisades. The Rocky Hill trap lies at a much higher horizon than the Palisades, but it descends rapidly eastward, and a continuation of this under the Cretaceous cover would readily unite it with the Palisades sill. Furthermore, the Rocky Hill sill increases in thickness eastward from its narrow outcrop near Hopewell, and a similar thickening is continued in the Palisades sill northward from Staten island and Bergen point.

The intrusive traps of Pennington and Baldpate mountains (*P* and *B*, plate 1) are doubtless continuous with the Rocky Hill sill, as also suggested by Darton, and are to be considered as lobe-like protrusions which probably merge into the same mass at no great depth. The irregular forms of these mountains and the northeastward apophysis of Rocky hill indicate subterranean branching of the lavas in this region.

* In the order given, the above data are recorded in the Annual Reports of the State Geologist of New Jersey for the following years: 1896, p. 199; 1904, pp. 265, 268; 1895, p. 93; 1898, pp. 131, 132; 1882, p. 59; 1895, p. 93; 1900, p. 159. The well near Woodbridge, however, was erroneously reported as southwest of the town.

The position of the Sourland Mountain trap, brought up by the Hopewell fault in a great repeated series of strata all dipping northwest, strongly suggests that it is also a part of the Palisades-Rocky Hill sill. If depressed some 6,000 feet, the approximate throw of the fault, according to Kümmel's estimate, it would fall into line with the probable subterranean continuation of the trap of Rocky hill and Pennington and Baldpate mountains. In a similar manner mount Gilboa, above Lambertville, and the smaller isolated trap mass at Byram, each lying on the upthrow side of a fault that repeats a large portion of the sedimentary series, may reasonably be regarded as fragments of the same sill brought up from near its thinner northwestern border (see cross-section along the Delaware river, plate 1).

Thus the correlation here advocated regards the intrusive trap masses outcropping in the Palisades, in Rocky hill, in Pennington, Baldpate, and Sourland mountains, in mount Gilboa, and the mass at Byram as parts of one continuous intrusive sill. Their present disconnected condition is due to the Cretaceous overlap in the case of the Palisades and Rocky hill, to lobe-like subterranean branching in Pennington and Baldpate mountains, and to repetition by faulting in Sourland mountain, mount Gilboa, and the Byram mass. Hence there is but one great intrusive sheet in the Newark of New Jersey in contrast with three considerable extrusives.

Offshoots of the Palisades sill.—Snake hill and Little Snake hill are two little knobs of trap that stand up prominently out of the Hackensack meadows at distances of a mile and three-eighths and one mile respectively from the western slope of the Palisades in Jersey City. If the Palisades trap continues approximately conformable to the sedimentaries under the meadows as it does along the Hudson river, it probably does not lie more than 1,600 and 1,300 feet respectively below the outcrops of the Snake hills, and it would be difficult to construct a section on this basis without connecting them with the great underlying sill.

The trap dike and intrusive sheet that form the small hill just north of Granton are about 800 feet from the nearest outcrop of the Palisades trap, but they are probably not more than 200 feet from the underlying portions of it and seem to be undoubtedly connected with it.

Similar dikes and sheets appear at the Arlington copper mines, 4 miles from the Palisades at Jersey City and 6 miles from the trap of First mountain at Montclair. It seems probable that these are also offshoots of the Palisades sill, which, with an average westerly dip of 12 degrees, would lie some 8,000 feet below; but even if the Palisades trap should

dip steeply downward from its western flank, as Darton supposed, these dikes and sheets would be much nearer it than to any probable feeding fissure for the extrusive sheets.

In like manner the dike at Bogota, the several dikes east, south, and west of New Brunswick, and those scattered over the region northwest of Sourland mountain are all most readily explained as thin offshoots from the same sill. In fact, some of these north of Sourland mountain have actually been traced by Kümmel to a direct connection with the great intrusive sheet at the outcrop, and there is little room to question that the others are of the same character.

The trap of Cushetunk and Round mountains.—These intrusive masses are of the same nature as the great Palisades sill and may be a contemporaneous upward protrusion of the same magma, but this question can not now be definitely determined. There is an interval of less than 3½ miles between Round mountain and the dikes about Flemington, which are undoubtedly offshoots of the Sourland Mountain trap. The structure about Cushetunk and Round mountains is complicated, and outcrops of the shales are too infrequent in the vicinity of the trap masses to permit satisfactory conclusions. Darton* concluded that we have here remnants of a wide intrusive sill "considerably flexed, and with the form of its present outcrops mainly determined by the removal of the trap from the crests of the anticlinals." Kümmel,† on the other hand, concluded that the curving outline of Cushetunk mountain "is not due, primarily at least, to an anticlinal or synclinal fold in the shales, but to the curving fracture through which the trap has come."

As to Round mountain, Kümmel considered it probably intrusive, but did not regard the evidence as definite as in some other cases. Metamorphic effects recently observed on the slopes of the mountain, however, leave no doubt as to the intrusive character, and this is in harmony with its prevailingly coarse granitic texture. The few observations possible seem to favor Darton's conclusion that Round mountain "lies in a well defined synclinal, or spoon, and is separated from Cushetunk by a local anticlinal" from which the intervening trap has been removed by erosion.

In the discussion of the Sand Brook and New Germantown extrusives above it has been shown that a former extension of the Watchung extrusive sheets over this region may reasonably be supposed. It is further shown below that the intrusives are probably of later date than the extrusives. If these conclusions are correct, it is possible that the upward movement of the Cushetunk and Round Mountain magma was

* Bull. U. S. Geological Survey, no. 67, p. 64.

† Annual Report of the State Geologist of New Jersey for 1897, p. 76.

stopped and its lateral extension determined by the overlying extrusives, which have since been removed from this region by erosion.

AGE OF THE EXTRUSIVES

From the position of the extrusive sheets near the top of the sedimentary series it is evident they were formed near the close of the period of deposition, so far as it is represented in the strata that now remain. It has been shown that the small remnants of extrusives at New Germantown and Sand Brook are approximately contemporaneous with the Watchung extrusives and possibly actual fragments of First and Second Mountain sheets. All extrusive activity was therefore very late in Newark time.

AGE OF THE INTRUSIVES

Several of the intrusive masses, as Rocky hill, Pennington, and Baldpate mountains, Cushetunk and Round mountains, penetrate strata far above the middle of the series, and Kümmel* states that "there are good reasons for believing that many, probably all, of the intrusive sheets are younger than the extrusive, although the evidence is not conclusive." He further suggests that intrusives were formed only after the overlying sediments became so thick that the lava could not readily rise to the surface.

According to any theory of deposition, however, the elevation of the surface did not vary greatly during the whole of Newark time, and therefore the force necessary to lift the lava to the surface would be little greater at the close of deposition than at its beginning.

Doubtless many of the deeper strata had become appreciably consolidated, however, before the close of the period, and the extrusive sheets, if of earlier origin, formed an additional barrier against further eruption. But there is also a strong tendency to intrusion inherent in the characters of the rocks themselves, and which must have existed even at the time of the extrusive flows. The specific gravity of the trap rocks averages about 3.0, while that of the inclosing sediments is near 2.5. Thus for every hundred feet in height of a column of lava there is an excess pressure of about 20 pounds per square inch over that of the inclosing strata, and this is the measure of the tendency to intrusion. A column of lava rising through 10,000 feet of sediments would thus exert an excess pressure of 2,000 pounds per square inch at the bottom of the series, and if it could be maintained stationary in a liquid state it would all force its way into the lower strata, lifting the overlying beds upon its surface.

A gentle welling up of lava under such conditions would perhaps always result in the formation of some intrusive masses, and the over-

* Annual Report of the State Geologist of New Jersey for 1897, p. 99.

flow would be roughly a measure of the force of eruption in excess of that required merely to sustain the column. Solidification of the sedimentary strata, in whatever degree, would also favor intrusion, unless the eruption followed a previously formed fissure, since cohesion is always less along bedding planes than across them. Overlying extrusive trap sheets, if present, would greatly augment these predisposing conditions due to progressive induration of the sediments and great difference in specific gravity, and might serve to divert an eruption of considerable violence into subterranean channels. It seems entirely probable, therefore, since the period of intrusion is known to have been in late Newark time, that it was subsequent to one or more of the extrusions and possibly contemporaneous with one of the later extrusives.

Furthermore, the investigation of the copper ores* deposited in many parts of the Newark in New Jersey has shown that the origin of many if not all of them is intimately connected with the intrusion of the great Palisades sill and its numerous offshoots; but the relations of some of these to the extrusive trap of First mountain are such that they could have been deposited only after the formation of the trap sheet and some of its overlying sediments. Hence these studies also have led to the conclusion that the period of intrusion was subsequent to at least the first extrusive flow.

On the other hand, several considerations make it clear that intrusion preceded the deformation of the strata by faulting:

(1) The numerous faults by which the traps, both extrusive and intrusive, are displaced throughout the area (plate 1).

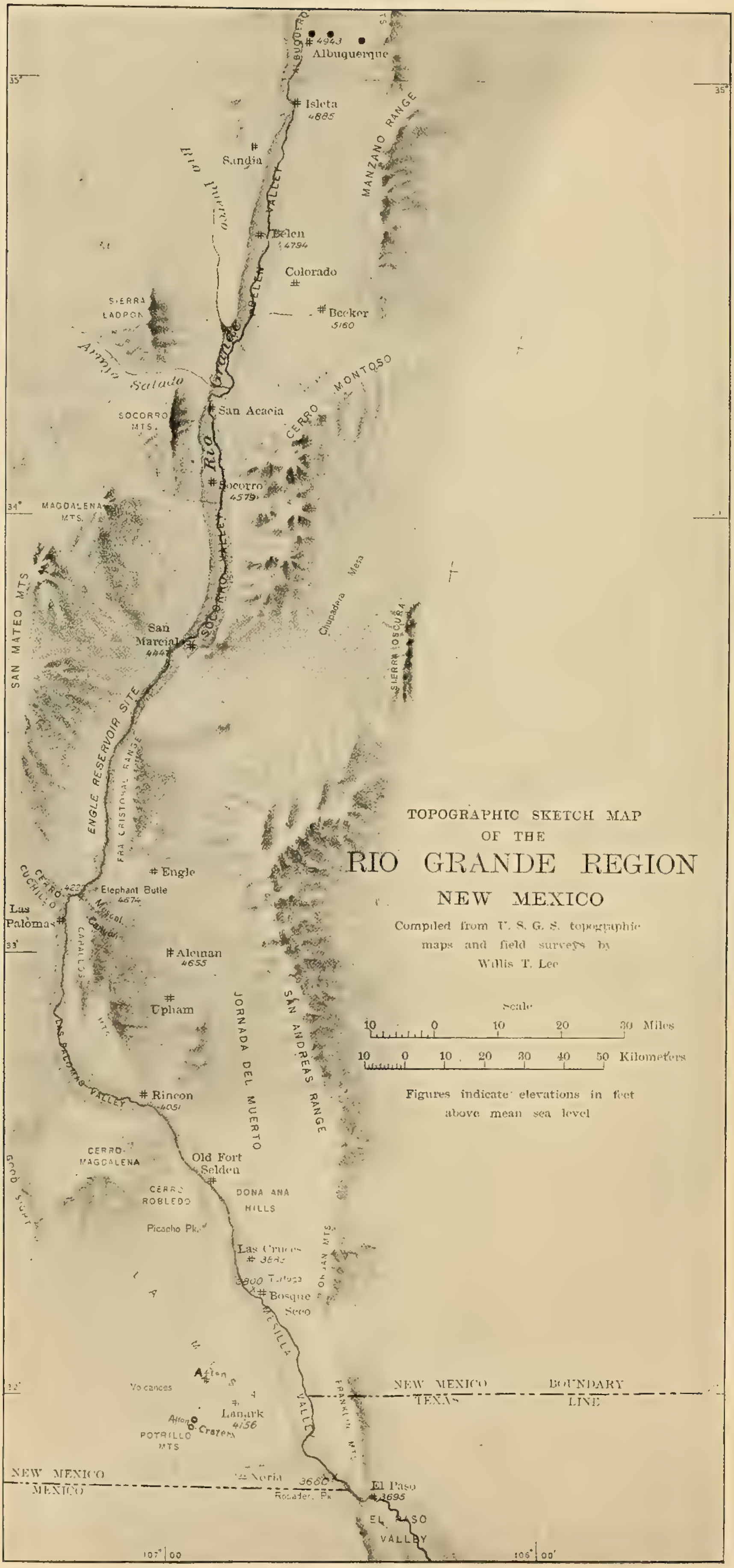
(2) The intrusives of Sourland mountain, mount Gilboa, and Byram are brought up in a great series of strata twice repeated by the Hopewell and Flemington faults.

(3) The western extremities of the Cushetunk Mountain trap seem to be determined by a fault or faults, probably northward extensions of the Flemington fault.

(4) Nowhere do the intrusives follow or send off branches along these fault fissures, and hence there is no evidence of igneous activity either during or subsequent to their development.

Thus all considerations agree in placing the date of intrusion after the formation of the first extrusive sheet and before the deformation of the strata by faulting and tilting. Possibly, therefore, the great intrusive sill is contemporaneous with one of the great lava flows of the second extrusive, or with the scant eruption of the third, or even subsequent to both.

* J. Volney Lewis: "The Newark copper ores of New Jersey." To be published in the Annual Report of the State Geologist of New Jersey for 1906.



MAP OF RIO GRANDE REGION, NEW MEXICO

Showing location of Afton craters

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AFTON CRATERS OF SOUTHERN NEW MEXICO*

BY WILLIS T. LEE

(Read before the Society December 29, 1906)

CONTENTS

General Description

During the summer of 1904, while engaged in geologic investigations in the Rio Grande valley in New Mexico, the writer visited the volcanic region about 30 miles northwest of El Paso and there examined the two depressions locally known as the Afton craters. These depressions, separated by about 2 miles, occur in the level plain, known as La Mesa, west if the Rio Grande and about 8 miles south of Afton, a station on the Southern Pacific railroad. The smaller, which is nearly circular in outline, is about a mile in diameter and has a depth of 150 feet below the general level of the plain. The larger is oblong, 2 miles in length and about 1¼ miles wide, with a depth of 250 feet below the surface of the plain. Each depression is surrounded by a rim varying in width from a few hundred feet to half a mile or more and rising 10 to 200 feet above the plain. The maximum difference in elevation between the bottom of

* Published by permission of the Director of the U. S. Geological Survey. Manuscript received by the Secretary of the Society March 2, 1907.

the larger crater and the top of the rim is 463 feet. For convenience of description the local names of these depressions may be adopted, the southern one being known as the Stehling crater and the northern and larger one as the Kilburn crater. They are essentially alike and the description applies to both, although the observations were made mainly at the larger or Kilburn crater. A sketch map and a section of the Kilburn crater are given in figure 1.

The sides of the depressions are steep and well exposed. The material beneath the general level of the plain consists of unconsolidated, but well stratified sand, with bedding undisturbed. No fragments of volcanic rock were found in these beds.

Above the stratified sand is a sheet of basalt having a maximum thickness of about 15 feet. This nearly surrounds the craters and extends eastward and northward over a considerable area. The rock contains but few gas cavities, is very compact, and is roughly columnar.

The circular rim is composed of sand, scoriaceous cinders, fragments of pumice, and angular blocks of basalt. The sand of which the rim is mainly composed is fine, loose, and generally unstratified, although in a few places near the base irregular bedding was noted, the layers sloping outward from the crater and being distinctly unconformable with the underlying sands. The volcanic cinders and fragments of pumice are intimately commingled with the sand and vary in size from that of sand grains to pieces an inch or more in diameter. The blocks of basalt, varying in diameter from a few inches to several feet, are embedded in the sand and cinders of the crater rims, and although they were noted in other parts are most numerous at the northern end of the Kilburn crater.

Probably the craters were formerly deeper and narrower than they are at present, as is indicated by the dotted lines in the section in figure 1, and have been partly filled by the falling in of the sides. The evidence of this is found in irregular mounds of sand and blocks of basalt fallen from the sides, and in the fact that small portions of the lava sheet are inclined inward, as shown in the section. Further evidence of such filling was obtained in drilling a well in the Kilburn crater by finding a piece of unpetrified wood at a depth of about 100 feet.

Geographic Features

In order to understand the significance of these depressions and to find a rational explanation for them, it is necessary to consider some of the surrounding conditions. These have been described in part in a

former publication,* to which the reader is referred for more extended statements than can be given in this connection. A brief summary, however, may be in place.

The plain in which the craters occur is the aggraded surface of the ancient valley of the Rio Grande. In common with the old valleys of the southwest generally,† that of the Rio Grande was filled with sand and gravel to a great though unknown depth in recent geologic time. It should be noted that the Rio Grande, as described in the paper just referred to, formerly flowed southward into Mexico across La Mesa west of Rodadero peak (or Cerro de Mulero, as the elevation is called by the residents of that region) and was deflected eastward at El Paso after the old valley had been filled with sand. This deflection may have been due to the building up of the valley floor until the level of the Pass was reached, or it may have been accomplished, as suggested by R. T. Hill, by the headward erosion of a gulfward-flowing stream which, after capturing the ancient Rio Grande, became the lower portion of that river as we know it at the present time.

After its deflection at El Paso the river eroded a secondary valley in the sand beds, leaving the aggraded surface, here about 20 miles wide, as a mesa plain 300 to 400 feet above the present river bed. The material composing the plain is so porous that the rain falling upon it sinks at once without forming even temporary drainage courses of any considerable length. The surface is therefore practically unaffected by stream erosion, but the sand at the surface is constantly shifted by winds.

The depth of the valley filling is unknown; wells nearly 1,000 feet deep do not reach through it, and in a neighboring valley near El Paso no solid rock was encountered at a depth of nearly 2,300 feet.‡ The depth to which the ancient valley of the Rio Grande has been filled is, therefore, probably much more than 1,000 feet, the greatest depth reached in the wells of La Mesa.

Geologic Conditions

QUATERNARY SANDS

The determination of the geologic age of the sands seems to fix within narrow limits the time when the craters were formed. In drilling a well in the Kilburn crater a fossil was found at a depth of 70 feet—330 feet below the general level of the plain—which Dr J. W. Gidley,§

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* W. T. Lee: Water resources of the Rio Grande valley in New Mexico. Water-supply and Irrigation Paper no. 188, U. S. Geological Survey, 1907, pp. 21.

† Compare W. T. Lee: Geology of the lower Colorado river. Bull. Geol. Soc. Am., vol. 17, 1906, pp. 275-284.

‡ G. B. Richardson: Reconnaissance in trans-Pecos, Texas. Bull. Univ. Texas, no. 23, 1904, p. 96.

§ Personal communication.

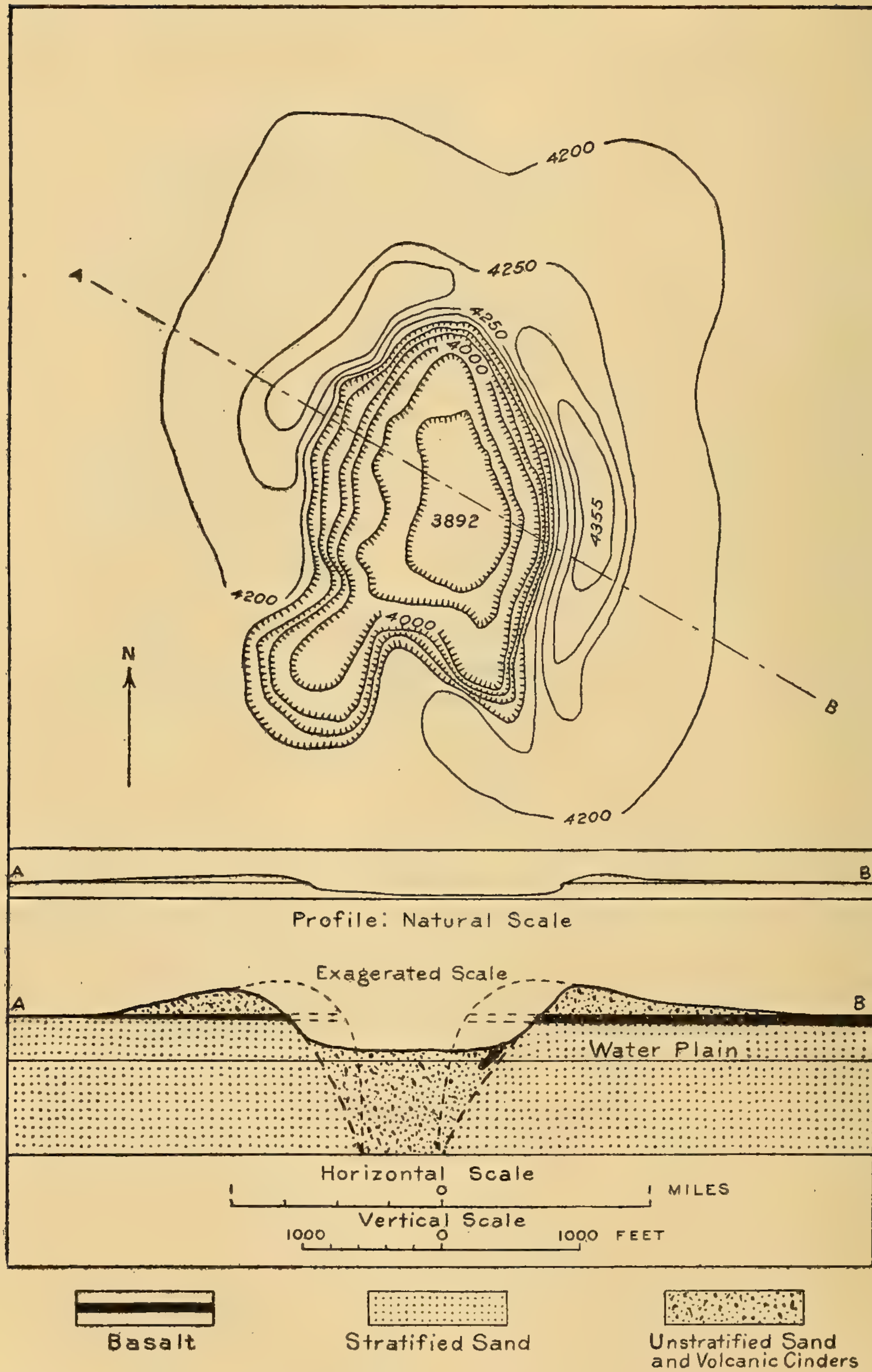

FIGURE 1.—*Contour Map and Cross-section of Kilburn Crater.*

Dotted lines of section indicate probable profile before outline was modified by caving of sides.

INTERIOR VIEW OF KILBURN CRATER

As seen from the southwestern part of the rim

of the United States National Museum, has determined to be a part of the jaw of a Pleistocene horse. It is probable that the fossil was not in place at this depth, for the crater has been filled to some extent by the caving of its sides, as previously described. The horse may have been entombed after the crater was formed, but a more probable explanation is that the bones, buried near the top of the sands previous to the formation of the crater, reached their present position through the falling of the sides.

About 200 miles farther north, in deposits similar to those found in Kilburn crater, Cope* found a number of Quaternary fossils, and more recently at Mastodon, a siding on the El Paso and Southwestern railroad between El Paso and Noria and 15 miles south of the Afton craters, bones have been found of two well known Pleistocene species, *Mastodon americanus* and *Equus complicatus.* These bones were found in a railroad cut by an employé of Mr H. J. Simmons, general manager of the El Paso and Southwestern railroad. Mr Simmons gave them to Dr G. B. Richardson, at whose request they were identified by Dr J. W. Gidley, of the U. S. National Museum. At El Paso, in beds which belong to the same horizon as those at the Afton craters and at Mastodon, and which are similar to them in physical character, bones have recently been found of three Pleistocene species, *Equus complicatus*, *Elephas columbi* (Mammoth), and *Tapiris haysii* (?). These bones were found by Mr Walter Kock in a gravel pit at El Paso, Texas, and given by him to Doctor Richardson,† at whose request they were identified by Doctor Gidley. The occurrence of these fossils in the sands proves that at least the upper part of the valley filling is Pleistocene.

On the other hand, the Santa Fé marls of the Rio Grande region of central New Mexico, described by Cope‡ as late Tertiary, do not differ notably in constitution or physical character from the Pleistocene sands. It would be exceedingly difficult without the aid of fossils to distinguish between these formations.

PRE-QUATERNARY FORMATIONS

The rock floor of the filled valley consists in part at least of Lower Cretaceous limestone and shale. Hill§ discovered the Comanche near

* E. D. Cope: Geographical explorations and surveys west of the 100th meridian, by Wheeler, annual report. Annual Report of the Chief of Engineers, U. S. Army, for 1875, Appendix LL, Washington, 1875, pp. 61.

† G. B. Richardson: Science, new series, vol. 25, 1893, pp. 31-33.

‡ E. D. Cope: Proc. Am. Phil. Soc., vol. 21, 1884, p. 308. See also Proc. Phila. Acad. Sci., vol. 26, 1874, p. 1471.

§ R. T. Hill: Bull. Geol. Soc. Am., vol. 2, 1891, pp. 517-518; also Am. Jour. Sci., vol. 45, 1893, p. 313.

El Paso, and Stanton and Vaughan* later described the section in detail. These rocks are exposed east of the old valley in the Rodadero peak near El Paso, and the writer found fossils near the northern end of the Potrillo mountains, a few miles southwest of the Afton craters, which, according to Stanton,† belong to the Fredericksburg group of the Comanche series. These rocks in many parts of southern New Mexico and western Texas are underlain by the Permo-Carboniferous red beds,‡ which are known to contain beds of salt and gypsum. The occurrence of the Comanche beds on either side indicates that the ancient valley is probably eroded either in this formation or through it into the Red beds. The probable occurrence of salt, gypsum, and limestone beneath the Afton craters will be referred to in considering the ways in which the craters may have been formed.

VOLCANIC ACTION

The Afton craters are located in a region of recent volcanic activity. Sheets of basalt cover a considerable area of the plain, which with their associated volcanic cones represent at least two periods of eruption. The older lava, one sheet of which is exposed in the Afton craters, is more or less eroded and partly covered with soil. The younger cones and associated flows have rough, unweathered surfaces and contain caves, open fissures, and other evidence of recent formation. Volcanic cinders are nowhere conspicuous. The cones are low, spreading, and composed almost exclusively of flow lava, little evidence of explosive action being found in connection with them. The flows are not notably scoriaceous and occur in broad, thin sheets, which suggest a very fluid and highly heated condition of the rock at the time of its extrusion. One of the smallest of the recent cones, having at the apex a depression about 100 feet in diameter, occurs between the two Afton craters.

TIME OF ERUPTIONS

The position of the older lavas above thick beds of Pleistocene sand proves that the time of their extrusion was long after the opening of the Quaternary. Judging from the evident difference in the amount of weathering of the lavas, a considerable length of time intervened between the two periods of eruption, rendering it probable that the last eruption

* T. W. Stanton and T. Wayland Vaughan: Section of the Cretaceous at El Paso, Texas. Am. Jour. Sci., vol. 1, 1896, p. 21.

† Personal communication.

‡ On account of the resemblance of these beds to the Red beds of eastern New Mexico and Texas, they have been frequently referred to as Permo-Trias. While some Permian red beds have been reported from the Rio Grande region, the great bulk of the red sandstones and shales are now known to be older than the Permian, as shown by the writer in a brief article in the Journal of Geology, vol. 15, 1907, pp. 52-58.

took place in very recent time, an inference which agrees well with the supposition that the Afton craters were formed during the second or latest period of volcanic activity.

Hydrologic Conditions

The valley filling is saturated with water below a depth of 100 feet beneath the bottom of the Kilburn crater, a level nearly corresponding with that of the river, as shown by wells sunk in various parts of La Mesa. The water obtained in the Kilburn crater is charged with hydrogen sulphide and has a temperature of nearly 100° Fahrenheit, 15° or more warmer than water from the same horizon in surrounding wells.

Other Depressions similar to the Afton Craters

Depressions resembling more or less closely the Afton craters have been described from several localities. Among those comparable in size with the Afton craters and most closely resembling them in character, two may be mentioned: Coon butte, near Flagstaff, Arizona, described by Gilbert* and others, which is a circular depression about 3,800 feet in diameter and 400 feet deep, surrounded by a crater rim 160 feet high, and Zuni Salt lake, in western New Mexico, described by Darton† and others, which is a nearly circular depression about a mile in diameter and 350 feet deep.

Comparable also, in some measure at least, are such volcanic phenomena as calderas like that of Crater lake in Oregon,‡ and the crater rings described by Russell§ from the Snake River region of Idaho, in which two depressions occur, the larger being 1,100 feet across and 200 feet deep.

Among other depressions which may be compared with the Afton craters are Montezumas well,‖ in Arizona, a circular depression about 600 feet in diameter and 170 feet deep, and Salt well,¶ in southern Nevada, 300 feet in diameter and 65 feet deep.

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* G. K. Gilbert: Science, new series, vol. 3, 1896, p. 1.

† N. H. Darton: The Zuni Salt lake. Journal of Geology, vol. 13, 1905, pp. 185-193.

‡ J. S. Diller and H. B. Patton: The geology and petrography of Crater Lake National park. Professional Paper no. 3, U. S. Geol. Survey, 1902.

§ I. C. Russell: Geology and water resources of the Snake River plains of Idaho. Bull. no. 199, U. S. Geological Survey, p. 110.

‖ William P. Blake: Origin of the depression known as Montezumas well, Arizona. Science, new series, vol. 24, 1906, p. 568.

¶ G. K. Gilbert: Wheeler Survey, Geog. and Geol. Survey West of 100th Meridian, vol. 3, Geology, 1875, p. 109.

Possible Causes of Formation

The principal hypotheses that have been developed to explain the various depressions above referred to are as follows:

1. The impact of a meteorite, originally suggested by Gilbert* and recently urged by Barringer† and Tilghman.‡
2. Explosion of steam or other gases, due to volcanic action.
3. Sinking of the surface, caused by the removal of underlying material by volcanic action, as in the case of calderas and crater rings.
4. Caving of the surface, due to the removal by solution of underlying material.

Choice of Hypotheses

Since no indication of the presence of an extra-terrestrial body has been found near the Afton craters, the first hypothesis can be dismissed without discussion.

The hypothesis of volcanic explosion (2) apparently explains most satisfactorily the observed facts. It is conceivable that explosions may have been caused by the sudden conversion of water into steam, following the entrance of molten lava into the water-saturated sands. The presence of extensive lava flows and large crater cones in the vicinity of the Afton craters shows that great quantities of extruded lava reached the surface in places. The cones vary greatly in size, and the smallest of them, in which only a slight quantity of lava reached the surface, is situated between the Afton craters. It is conceivable that in the case of the Afton craters lava was thrust into the water-bearing sands, but failed for some reason to reach the surface. In other words, these craters may represent one of the first stages of volcanic action in this district. It is probable that at one time the other craters presented some such aspect as the Afton craters now show, and the later eruptions filled the depressions with lava and finally built volcanic cones.

The composition of the crater rims proves beyond reasonable doubt that the material came from beneath. The supporting facts already stated may be summarized as follows: The rims are composed of an intimate mixture of fine sand, volcanic cinders, and blocks of lava, the volume of sand greatly exceeding that of the cinders. The cinders are highly scoriaceous, thus differing notably from the older compact flows—a fact apparently unfavorable to the supposition that the cinders may

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* G. K. Gilbert: Science, new series, vol. 3, 1896, p. 1.

† D. M. Barringer: Coon mountain and its crater. Proc. Acad. Nat. Sci., Philadelphia, 1905, pp. 861-886.

‡ B. C. Tilghman: Coon butte, Arizona. Proc. Acad. Nat. Sci., Philadelphia, 1905, pp. 887-914.

have been formed by the rupture of previously hardened lava. The specimens collected for examination were found to have the same megascopic and microscopic appearance as cinders from volcanic cones and gave no evidence for or against the hypothesis suggested.

The presence of the angular blocks of basalt in the rims can be satisfactorily accounted for only on the supposition that they came from the underlying basalt sheet. No sand mounds were found elsewhere on La Mesa which are at all comparable in elevation with the crater rims; hence there is nothing to suggest that the rims are in any sense remnants left by a general degradation of the plain. There is, furthermore, good evidence in the general character of the plain that its present surface is essentially the same as that originally formed by the deposition of the sands.

Apparently the only objection to the explosion hypothesis is the probable discrepancy in volume between the craters and the rims. The volume of the rims is apparently less than that of the depressions from which the material is presumably derived, but a measure of the difference can be given only after much more detailed surveys have been made. As previously stated, however, the action of the wind is adequate to account for a considerable diminution in the size of the rims. The importance of the wind as a transporting agent in this region is shown by the great quantities of drifting sand and by the numerous areas of gravel due to the surface concentration of coarser material that are found in many places on the surface of La Mesa. It is not improbable that the crater rims may originally have been volumetrically equal to the depressions and have been diminished to their present volume wholly through wind action. A certain amount of diminution by this means is proved by the fact that the rims are covered more or less completely with fragments of lava, small pebbles, and sand too coarse to be readily moved by winds.

It is furthermore probable—and for this suggestion I am indebted to Dr Whitman Cross—that explosions having force sufficient to blow out such large craters would throw much of the material too far away to be included in a recognizable rim.

The other two hypotheses may be possible, but can scarcely be considered probable. The presence of the craters in a volcanic region within a few miles of vents from which considerable quantities of lava have been extruded is in some measure favorable to the third hypothesis. The fact also that the volume of material in the crater rims is apparently less than that of the depressions might be interpreted as favorable to this hypothesis, were it not for the more probable explanation just given.

The hypothesis (4) of caving due to solution of underlying beds, while theoretically possible, finds little more support in observed facts than the one of sinking caused by the removal of underlying volcanic rock. Probably the strongest points that might be urged in its favor are: First, the volumetric discrepancy between the rims and the crater depressions, and, second, the probable occurrence beneath the plain of the salt, gypsum, and limestone deposits of the red beds, the subterranean solution of which has elsewhere produced notable sinks. The first has been sufficiently discussed, but further attention should be given to the second.

Montezumas well, in central Arizona, is presumably due to the solution of underlying limestone, as explained by Blake in the article previously cited. Salt well, in southern Nevada, and to some extent at least the crater of Zuni Salt lake of western New Mexico, are explained by the geologists who have described them as occasioned by the solution of underlying beds of salt. The removal of gypsum by subterranean solution is also known to have produced remarkable sinks, notably in Pecos valley, eastern New Mexico, as described by Fisher* and by Lee.†

Opposed to the hypothesis of subterranean solution, however, is the probable depth of the salt and gypsum. As previously described, the sands of the valley filling are at least 1,000 feet thick and probably rest on Lower Cretaceous strata of unknown thickness. The nearest outcrops of the Red beds indicate that 1,000 feet or more of strata intervene between the salt and gypsum horizons and the overlying Cretaceous beds. It is probable, therefore, that the salt and gypsum, if present beneath La Mesa, lie too deep for their solution to have been effective in forming the Afton craters.

Conclusion

The observed facts all point to the hypothesis of volcanic explosion as giving the most rational explanation of the Afton craters. It is furthermore probable that the explosions were caused by the formation of steam generated by lava that was forced into the water-saturated sands, but that failed to reach the surface. The probable presence of this lava, still retaining its heat in some measure, is indicated by the occurrence of the warm well-water in the Kilburn crater.

* C. A. Fisher: Geology and underground waters of the Roswell artesian area, New Mexico. Water-supply and Irrigation Paper no. 158, U. S. Geological Survey, 1906.

† W. T. Lee: Gypsum beds and water storage in the Pecos valley of New Mexico. Science, new series, vol. 23, 1906, p. 306.

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CONDITIONS OF CIRCULATION AT THE SEA MILLS OF CEPHALONIA*

BY MYRON L. FULLER

(*Read before the Society December 29, 1906*)

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Introduction

Near Argostoli, on the southern coast of the island of Cephalonia, in Greece, a stream of salt water has for an unknown period of time left the almost tideless sea, and, flowing inland with a volume sufficient to furnish water power to two mills, finally disappeared in fissures representing enlarged joint cracks in the limestone. This remarkable reversal of the normal conditions of drainage and the disposal of the immense quantities of water sinking into the limestone have long been themes for speculation. It remained for F. W. and W. O. Crosby,* however, to offer

* Manuscript received by the Secretary of the Society April 19, 1907.

* The sea mills of Cephalonia, Technical Quarterly, vol. 9, 1896, pp. 6-23.

the first plausible explanation, which, in brief, is the differential action of the earth's interior heat on an unsymmetrical passage with a short "inlet" and a long "outlet" arm, the water in the latter, because of its greater exposure to the heat, being warmer and lighter than in the short arm, thus establishing the necessary conditions for circulation.

The object of the present paper is to call attention to another possible, but heretofore unrecognized, factor in the circulation, namely, the difference in the density in different parts of the passage due to an admixture of fresh water with the salt. Both heat and dilution may unquestionably be real causes of circulation of the Cephalonia type, and it only remains to determine their relative effectiveness and probability. In doing this we must rely on the evidence afforded by the local conditions in the Cephalonia region, especially in regard to the neighboring springs, and on our general knowledge of the nature of deep circulation.

The writer wishes at this point to express his thanks to Professors W. O. Crosby and J. F. Kemp for a number of suggestions, and to acknowledge his indebtedness to the paper cited for the descriptive data relating to the mills.

General Conditions

LOCATION

The town of Argostoli, near which the sea mills are located, is situated on the southwest side of Cephalonia, an island some 20 miles in length lying off the gulf of Patras, on the west coast of Greece. Speaking more exactly, it is situated on the inner side of a low, narrow peninsula of limestone projecting northward from the east side of the gulf of Argostoli, and forming the harbor toward which the town faces. The two sea mills are at the extremity of this promontory, about a mile north of the town. The first mill to be seen is that of Doctor Migliaressi, established in 1859; the second, erected by Mr Stevens, an Englishman, in 1835, is a quarter of a mile farther on and near the end of the point. The mills, when in operation, took their power from undershot wheels driven by a current of salt water conducted from the sea by an artificial channel. They have now been abandoned, however, for some time, owing to the competition of larger and better equipped mills elsewhere.

NATURE OF THE PHENOMENA

Originally, according to the descriptions of Professor D. T. Anstead in his book on the Ionian islands (page 322), the sea at its ordinary level entered the land at four points, forming a narrow creek which

flowed a short distance in a broken rocky channel before being absorbed by the limestone. No natural streams are now to be seen, their place being taken by the artificial channels leading to the mills, although, according to Crosby and Crosby, absorption continues to take place not only over the whole surface between the two mills, but also along the coast for nearly half a mile, the water everywhere percolating through the cracks and fissures of the limestone and sinking into the earth. Still larger quantities are possibly absorbed from the surrounding sea bottom. Nor is the phenomena apparently confined to Argostoli, for Reclus, in his volume "The Ocean," states (page 146) that the feature may be observed at various points on the coasts of calcareous countries, especially on the coasts of Greece and the neighboring islands. The volume is given by Reclus as 55 gallons per minute, but the flow taken by Crosby and Crosby for their calculations is about 33 gallons per minute. The latter, however, does not appear to be based on actual measurements. When the second mill was built, according to the same authorities, the power of the old mill diminished, indicating that no additional water was being taken from the sea, from which it is concluded that the entire inflow is tributary to a single subterranean channel. The artificial flumes mentioned are two in number, 4 to 6 feet in breadth, and slope inland to pits sunk in the limestone beyond the mills, the bottoms of which are 3 feet or more below sealevel.

TOPOGRAPHY AND GEOLOGY

The peninsula which has been mentioned as the site of the sea mills is composed of bluish-white Cretaceous limestone nearly destitute of vegetation and with a rough and rugged surface due to differential weathering. At the northern extremity of the promontory, in the vicinity of the mills, the surface is low and flat, but gradually rises to the southward, reaching a height of 200 or 300 feet or more at a distance of 5 or 6 miles. This Cretaceous limestone appears to be some thousands of feet in thickness, and forms almost the entire surface of Cephalonia, Zante, and other neighboring islands, as well as many hundreds of square miles on the mainland to the east. H. E. Strickland* described it as "a hard, white limestone, abounding in faults and fractures, as well as caverns, subterranean rivers, and thermal and mineral springs." Crosby and Crosby further state that limestone caverns are numerous throughout Cephalonia and some deep sinks occur. In boring a well at Argostoli, about a mile from the sea mills, a cavern 200 feet in height was encoun-

* Proc. Geol. Soc. London, vol. 2, 1835, p. 572.

tered at a depth of 225 feet, or well below the level of the surrounding sea (P, figure 2). The Cretaceous limestones, according to descriptions, appear to lie on ancient crystalline rocks.

SPRINGS

Inasmuch as the water entering the limestone at the sea mills must reappear at the surface elsewhere—possibly even above sealevel—the occurrence of springs is of special interest. According to all authorities, however, there are no saline or thermal springs on the island of Cephalonia, nor on the adjacent portions of the mainland, although in other parts of Greece, especially in the eastern portion, a considerable number of brackish springs discharge continuously enormous volumes of water,* but they do not appear to be noticeably thermal. Thermal springs are, however, found at a number of points, including several on the island of Eubœa, in eastern Greece.

NATURE OF THE FISSURES

The water at the sea mills seems to follow enlarged joint cracks, and it is probable that parts of the deeper passages of the circulating system are of the same origin. Crosby and Crosby, however, lay great stress on the action of earthquakes. These are very numerous and of great severity, and some of them apparently have had their foci at no great distance from Cephalonia. Marked fissuring has accompanied several of the disturbances elsewhere in Greece, and some springs have ceased to flow, while others have had their discharge greatly increased. That the waters reach considerable depth in the fissures is shown by the temperatures, which in eastern Greece are as high as 82° centigrade in some instances.

Possible Causes of Circulation

UNDERGROUND PASSAGES

The flow at the sea mills, which has continued for an unknown period of time—almost certainly for several centuries—is far too great for removal by evaporation, chemical combination, or even physical absorption by pores or caverns in the rocks, and the constant influx can only be satisfactorily explained on the hypothesis that the passage into which the water disappears is a part of a definite circulatory system through which the water passes to some point of emergence, which, whether it be above

* Crosby and Crosby: Loc. cit., p. 18.

or below the sea, must be, from the hydrostatic standpoint, at a greater elevation, since the head at the mills is 3 feet below sealevel.

EFFECT OF TEMPERATURE

In order that circulation may be established through the agency of the interior temperature, unequal heating of the water in the circulatory system must take place. This might result from a relatively strong application of heat at a particular point, as in the vicinity of an igneous intrusion, or, on the other hand, it might be due to the action of uniform heat on an unsymmetrical passage, as in figure 1, in which the dotted line represents a horizontal isogeotherm. In igneous intrusion we have a possible cause, but of its actual existence there is no positive evidence. The horizontal isotherm, on the contrary, is the normal condition. It is evident that with the arrangement shown in the figure the water in the

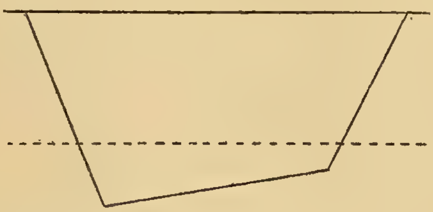

FIGURE 1.—*Conditions of Thermal Circulation* (*Crosby and Crosby*).

long, gently inclined arm is much more exposed to the action of high temperatures than that in either of the more nearly vertical arms, the result being to decrease its density until movement is set up by virtue of the excess of pressure of the colder and heavier water in the left arm. As is pointed out by Crosby and Crosby, this is certainly not an improbable arrangement and provides the mechanism for a strong circulation of water.

EFFECT OF DILUTION

Amount of dilution necessary.—To establish circulation without the agency of heat, a slight dilution of the water is all that is necessary. The specific gravity of the sea water of the Mediterranean is 1.03; hence a column of salt water 100 feet in length would support a column of fresh water 103 feet high. Of course, the existence of an absolutely fresh column balanced against a purely salt column is out of the question in a circulation system of the Cephalonia type; but fortunately such conditions are unnecessary, for even with a dilution of only 10 per cent a depth of 100 feet would give a working head of .3 foot, which would be sufficient to establish the conditions for circulation. With a 25 per cent

dilution, a similar working head might result from a depth of less than 50 feet, while with 50 per cent dilution only 25 feet would be necessary.

For the production of circulation by differences in density due to dilution, no particular arrangement of the fissures is necessary and no great depth is required, it being possible with a dilution of 25 per cent to develop a head sufficient to produce circulation at a depth of less than 50 feet, or entirely above the zone controlled by interior temperatures.

Inevitableness of dilution.—The studies of the waters of deep mines and tunnels on the one hand and of the underground waters in sedimentary rocks as developed by deep borings on the other tend to show that, except in the case of dense and fracture-free rocks, all formations are commonly saturated from the water table down to considerable depths, the water movement, according to the laws of underground waters, which—thanks to King, Slichter, and others—are almost as well known as those of surface streams, being toward the lowest point of possible leakage, which in the case of Cephalonia must be toward the sea. Cavernous limestones are no exceptions to the rule of saturation, nor to the normal seaward movement of the water, and there is little reason to doubt that the rock passages, with which the Cephalonia limestone abounds, are filled in a large measure with fresh waters moving toward the sea. The prevalence of this movement near the sea mills is rendered more probable by their position near the apex of a large reentrant bay, the gulf of Argostoli, toward which the subterranean as well as the surface drainage would naturally tend to converge. Besides this underground drainage from the land, considerable amounts of fresh water must reach the subterranean passages through sinks, joints, or crevices, which are a characteristic feature of the limestone in the immediate vicinity, the rugged fissured surface of which has already been noted. Not only is there in all probability a considerable circulation through the limestone, but there is reason to believe that the network of passages is so complete that the dilution of any salt water entering the rock is inevitable. Besides the bedding and joint planes, which doubtless determined the location and controlled the formation of many of the passages, there are many indications that earthquakes have done much to unite them into a connected system of openings. Elsewhere in Greece earthquake shocks have produced far-reaching effects upon the underground drainage, old springs being destroyed in some cases and doubled in volume in others; new springs have broken out, and the waters of old springs have changed in character and temperature. The Cephalonia region is likewise one of violent earthquakes, some of disastrous severity having

been felt in very recent years, and, although full data are not at hand, it is more than probable that fractures have been produced by these or similar shocks in the past. These can not fail to be of importance in connecting the solution passages with one another. The intimate connection of the passages, making to all practical purposes a network, has been brought out at several points in this country by the experiments made for the United States Geological Survey by S. W. McCallie at Quitman, Georgia; by E. H. Sellards at Ocala, Florida, and by G. C. Matson at Georgetown, Kentucky, at each of which localities salt inserted into sinks or borings found entrance into wells some distance away. In none of the instances, however, was the movement direct from the point of insertion to the well, for the salinity, instead of increasing enormously, as it would have done if such had been the case, showed only relatively moderate fluctuations. The three limestones, although of widely different types, showed the same phenomena in each case, suggesting that it is a normal characteristic of this class of rocks.

If such a network of passages exists at Argostoli, as in all probability it does, it follows that it would be practically impossible for a single passage bearing the water to maintain an independent existence to any considerable depth. The encountering of fresh water passages under such conditions and a mixing of the waters seems inevitable.

Conditions of dilution.—When the salt and fresh waters meet, one or the other of two things will happen: Either the salt water will be forced upward by a longer column of fresh water or the fresh water will be forced back by the salt. Which of the two occurs will depend on the relative heads of the salt and fresh waters. In this connection it should be noted that the phenomena of the sea mills is one occurring at the borders of the sea toward which the underground waters are moving and which marks their points of escape. From this it follows, in accordance with well known laws of artesian circulation, that the head of the fresh water will be very low at this point, even if the original source is in regions of considerable elevation. Under such conditions and with the juncture of the fresh and salt water passages occurring at a depth of a few hundred feet, the weight of the salt water may easily be such as to counterbalance the head of the fresh water column.

The supposed conditions of circulation can be better shown by the aid of the following diagram (figure 2) than by extended description. In the figure SM shows the situation of the sea mills; P, the trunk subterranean channel fed by crevices; the vertical lines at P, the well at Argostoli; M, the mainland of the island of Cephalonia from which the water

latter may not be considerably longer, as would naturally be the case if derived from the highlands of the mainland. This point is brought out by figure 3, which shows a circulatory system in which F is the fresh is presumably derived, and S, the silts which prevent communication with the sea.* In order that the salt water may commingle with the fresh, it must have, as just indicated, a weight at least equal to that of the fresh water, although this does not mean that the length of the column of the

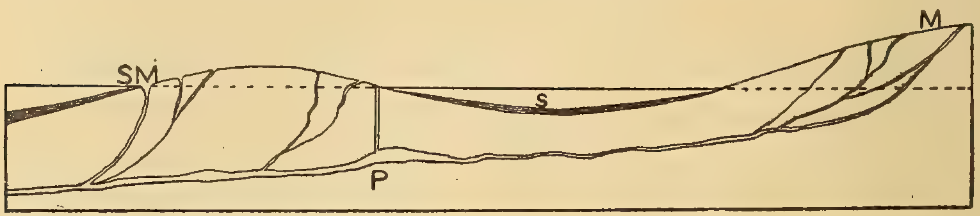

FIGURE 2.—*Diagram showing supposed Conditions of Circulation at the Sea Mills of Cephalonia.*

water column, 103 feet in height and rising 3 feet above the salt water inlet; S, the salt water column, 100 feet in height, and M, the mixed column. Under such conditions the waters would mix in equal proportions (50 per cent dilution of the salt water), giving to the outlet column (M) a head of 1½ feet, or more than enough to establish the conditions essential for circulation. With a salt column 1,000 feet in height, the fresh column would be 1,030 feet and the mixed 1,015 feet in height.

If the fresh water column is of greater weight than the salt water col-

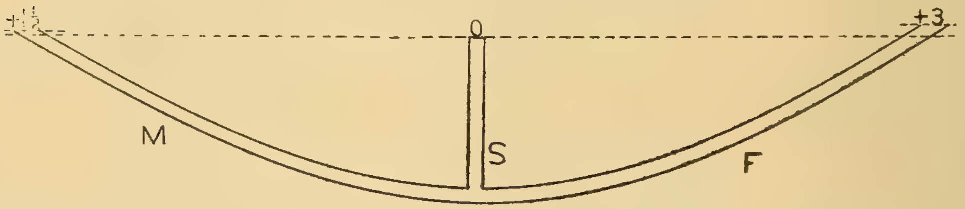

FIGURE 3.—*Conditions of Head in Circulation System with fresh (F), salt (S), and mixed (M) Columns.*

umn, the water of the latter will be forced back and a spring result. If, however, the salt water column is heavier than the fresh water, the latter, having no outlet, will tend to rise until its pressure so nearly approaches that of the salt water column that intermixture begins. Once started, the circulation is facilitated by the lower density of the resulting mixture,

* In order to show the supposed conditions by a single section, certain generalizations were necessary. In reality M, P, and SM are not in a straight line, the direction from M to P being southeast and northwest, while that from P (Argostoli) to SM (at the northern end of the peninsula) is considerably more northerly.

and will continue as long as the pressure of the fresh water column is not in excess of that of the salt water.

Under normal conditions, when the pressures are approximately in equilibrium, a 50 per cent dilution of the salt water will result if the passages are of the same size. It may be conceived, however, that the fresh water channel is only half the size of that of the salt water, in which case, although the pressures might be in equilibrium, the mixture would no longer be composed of equal volumes of the two, but of $\frac{2}{3}$ salt water to $\frac{1}{3}$ fresh water. With a large fresh water passage and a small salt water passage, the reverse would be true.

The point of emergence has much to do with the nature of the circulation. Strange as it may seem at first sight, an outlet above the level of the sea is more favorable than one considerably below it. The conditions may perhaps be made more clear by reference to figure 3. In this figure the outlet is indicated as occurring at a point above the level of the sea under conditions where the full benefit of the low weight of the diluted column is obtained. If, instead of this arrangement, the outlet in the same system were as low or lower than the bottom of the salt water inlet column (S), the downward pressure of the sea on the outlet would be greater than that in the underground channel and no flow would result. It is apparent, therefore, that, inasmuch as the weight of the fresh water column (F) can not be greater than the salt water column (S) except where the outlet is hydrostatically lower than either, the circulation system at Cephalonia must in all probability terminate at or near sealevel.

It has been suggested to the writer that an inflow of the Cephalonia type should, under the dilution hypothesis, vary with seasonal changes of the fresh water supply. In reality deep seated waters almost nowhere show any material variation with seasons, the fluctuations being practically limited to the upper part of the unconfined surface body of ground water. As long as the head of the salt water column equals or exceeds that of the fresh, as it must in order that circulation may exist, it will control the circulation and no variation will be noted.

An alternative hypothesis which has also been suggested to the writer assumes the influx of the salt water to be due to suction, the action being analogous to the indraft of air produced by the water jet in the Richards suction apparatus of our chemical laboratories or to that produced by the steam jet in boiler injectors. The former process is known to produce a strong and continuous suction of air in some cases,* but the conditions

* M. L. Fuller: Indraft wells in southern Georgia. Science, new series, vol. 23, 1906, p. 140.

of the latter are not likely to be duplicated in nature. The hypothesis appears to be untenable as an explanation of the circulation at Cephalonia for the following reasons: (1) Air currents of any strength in underground passages must be the result of water movements rather than *vice versa,* so that even if air were present no suction giving rise to an indraft of water could be produced;† (2) the underground passages below the sea or ground-water level are necessarily completely filled with water, thus precluding the existence of air other than as an included gas incapable of producing currents; (3) no high velocities are possible in underground passages below the water table, where, as at Cephalonia, only moderate heads are available; and (4) the postulated suction can not, according to the laws of hydrostatics, take place between two liquids like those at Cephalonia, which have, as has been pointed out, substantially equal heads.

Source of water.—If the depth at which the commingling of salt and fresh waters takes place were known, an estimate of the head, and indirectly of the source of the fresh waters, could be made. The point of union apparently can not be excessively deep, as the limestone is probably not over a few thousand feet thick. It is probable that the water comes from the island itself, most likely within a few miles of the sea mills, rather than from the mainland, some 30 miles away.

Point of emergence.—It is a matter of observation that there are no large saline springs near at hand, either on Cephalonia, Zante, or on the adjacent portions of the mainland, making it almost certain that the outlet is at some point beneath the sea. If the outlet were in very shallow water, near shore, it could hardly have escaped recognition. As has been pointed out, however, the weight of the overlying body of sea water will oppose the emergence of the mixed column if the outlet is below sealevel, the pressure to be overcome by the latter being equivalent to 1½ feet of its head for every 100 feet of depth of the sea. If, therefore, as is usually the case, the head of the underground water at the coast is low, it will follow that the point of emergence can be at no great depth and probably at no great distance from the sea mills.

RELATIVE COMPETENCY OF TEMPERATURE AND DILUTION

Something of the relative competency of temperature and dilution has been indicated in the course of the foregoing description, but it is more forcibly brought out by the following table:

† Air currents such as those flowing in and out of caves are too feeble to produce any material suction.

Table showing Lengths of diluted and heated Columns under varying Conditions of Dilution and Temperature.

Diluted column.					Heated column.			
Height of supporting column of salt water.	Per cent of dilution.				Assumed depth of circulatory system.	Assumed average temperature of rocks penetrated.	Assumed difference of temperature in long and short arms.	Length of columns supported at different temperatures.
	90.	75.	50.	25.				
Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Degrees F.*	*Degrees F.*	*Feet.*
100	102.7	102.2	101.5	100.7	100	64	1	100.01
500	513.5	511.2	507.5	503.7	500	69	5	500.3
1000	1,027.0	1,022.5	1,015.0	1,007.5	1,000	74	10	1,001.2
1500	1,540.5	1,533.7	1,522.5	1,511.2	1,500	79	15	1,502.9
2000	2,054.0	2,045.0	2,030.0	2,015.0	2,000	84	20	2,005.4

Attention is called to a few significant points brought out by the table. For instance, it appears that a 50 per cent dilution of a salt water column at 63° Fahrenheit (the mean temperature of Argostoli) will increase its head 1½ feet for the first 100 feet, while the increase due to 1° difference of temperature is only 1/100 of a foot, or 1/150 of the difference due to dilution. Again, the increased head due to a 50 per cent dilution in a 2,000-foot column is 30 feet, while the temperature increment (between 64° and 84°) is only about 5½ feet, and so on. The table also brings out the fact that to bring about a flow at sealevel, it being recalled that the inlet is some 3 feet below sealevel, a depth of 1,600 feet is required on the temperature hypothesis, while on the dilution hypothesis only 200 feet is necessary.

Conclusions

The constant influx of salt water at Cephalonia is unique, being duplicated, so far as authentically reported, at no other point in the world. It is not, therefore, to be expected that simple conditions, such as might be reproduced at numerous points, will be found to exist at the sea mills, for otherwise the phenomena would be almost certain to be found elsewhere. It does not follow, however, that because some of the attendant conditions are peculiar to the Cephalonia locality that the ultimate causes are not of a simple and commonly recognized type. Both temperature and dilution appear to be fully competent to produce circulation of the kind observed at Cephalonia, but each requires the existence of cer-

tain special conditions without which it can not act. In the case of the first, either an unsymmetrical passage of a form specially adjusted to the development of a higher temperature in the outlet than in the inlet arm, or an unequal distribution of heat, is necessary, while in the second the heads of the fresh and salt columns must be essentially balanced. From the underground water standpoint neither supposition is inherently improbable. Temperature can hardly fail to act if the water reaches to any considerable depth, while dilution may be a factor at any depth. The writer believes that such dilution is inevitable, and that while the heat hypothesis is by no means improbable, that of dilution is to be regarded as a possible alternative. If dilution occurs at all, it will of necessity be several times as effective as heat.

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ORIGIN OF OCEAN BASINS IN THE LIGHT OF THE NEW SEISMOLOGY*

BY WILLIAM HERBERT HOBBS

(Read before the Society December 28, 1906)

CONTENTS

Usual Arguments for Antiquity of present Ocean Basins

The doctrine that the present ocean basins came into being at an early stage of the earth's history we owe especially to James D. Dana† and Charles Darwin,‡ though there have been many followers. The facts and supposed facts on which this theory was founded have for the most part either been modified or given a different interpretation during the time which has since elapsed. Moreover, the new seismology—the study of earthquakes from a distant station—seems now to be furnishing new

* Manuscript received by the Secretary of the Society March 2, 1907.
† Am. Jour. Sci. (2), vol. 2, 1846, p. 352. Manual of Geology, sixth ed., pp. 815-817.
‡ Origin of Species, first ed., p. 343.

and valuable data for a solution of the question of age of the present ocean depressions. Many of the arguments once urged in support of the antiquity of the present basins, interpreted in the clearer light of today, inveigh against it. These arguments have perhaps nowhere been better stated than in the anniversary address of the late Professor W. T. Blanford before the Geological Society of London.*

The arguments for the permanency of the present ocean basins are:

I. The supposed absence of continental rock types from oceanic islands, thus allowing it to be inferred that the ocean bottom, like the islands themselves, is composed of heavier volcanic rock.

II. The abnormal gravity values obtained in pendulum observations made within the infra-continental zones and supposed to be influenced by a heavier stratum of rock which occupies the ocean floor.

III. The general absence of typical deep-sea deposits from the continental areas.

IV. The supposed restriction of related faunas and floras to the same continent.

Supposed Absence of continental Rocks from oceanic Islands

As regards the first mentioned argument, more non-volcanic oceanic islands have been explored since the doctrine was first brought forward, and there have been discovered in the lavas of oceanic islands inclosures of rocks belonging to the continental types; which discoveries have removed much of the force of the argument.

Most of these oceanic islands project above the surface of the sea as the upper parts of the highest volcanic accumulations. Examination of volcanic districts upon the continents speaks for a basement of non-volcanic material. Should the cinders be largely submerged the high volcanic peaks would be the only parts exposed above the sea.

Abnormal Gravity within infra-continental Belts

The writer has elsewhere† drawn attention to the many cases in which derangement of the gravity constants appears to be associated with earthquake zones and dislocation belts and the way in which this phenomenon appears to be related to magnetic disturbances. If it be true that the crust adjusts itself to the secular cooling in compartments bounded by faults (which occasionally are laid bare at the surface), and if, further, it be true that the dense core of the lithosphere (specific gravity, 5.6) is

* Quart. Jour. Geol. Soc., vol. 46, 1890, pp. 60-110.
† Gerland's Beiträge zur Geophysik, vol. 8, 1906, heft 2, pp. 271-277.

separated from the surface by only a few miles of the much lighter crust (specific gravity, 2.7), then any considerable vertical adjustment of adjacent blocks should disturb the gravity constants for points located near the bounding faults. In Italy especially has a fourfold correspondence of earthquake districts, fault zones, zones of abnormal gravity, and abnormal earth magnetism been established.* There is in this an adequate explanation of the abnormal values of gravity within the infra-continental zones, if it be true that the ocean basins be bounded by dislocations on which large movements have occurred.† An extended questionnaire by Milne has further shown‡ that of the earthquake stations supplied with magnetometers whose work is correlated under the British Association, magnetometers are chiefly disturbed where the gravity constants show abnormal values. Since 1888 continuous observations with magnetic instruments have been made in Japan, and since 1898 at five stations well distributed over the country. On several occasions magnetic disturbances seem to have preceded or accompanied earthquakes.§ It has been shown that the depth or height from the station of the source of the disturbance is small compared to the distance between the stations.

General Absence of deep-sea Deposits from continental Areas

The *Challenger* observations have satisfactorily explained this by showing that no deposits are now forming over large areas of the sea-floor, save only the red clay, which is probably largely of meteoric origin. Corroded teeth of an extinct species of shark have been dredged up from great depths, and show that for ages no deposits have there formed of sufficient thickness to entomb them.

Significance of faunal and floral Distribution

It is the fourth of the arguments urged in support of the antiquity of the ocean basins, namely, the restriction of related faunas and floras to the same continent, which especially needs revision for the Tertiary and later periods. In the language of Blanford,‖ "If we wish to know anything about ancient distribution of land and sea, we must scrupulously

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* A. Ricco: Comptes Rendus Acad. Sci., Paris, vol. 137, 1903, p. 827.

† See On some principles of seismic geology. Beiträge zur Geophysik, vol. 8, 1907, chap. viii.

‡ John Milne: The Geographical Journal, London, 1903, pp. 15-18.

§ Kikuchi: Recent seismological investigations in Japan. Pub. E. I. C., foreign languages, no. 19, 1904, pp. 80-81.

‖ Loc. cit., p. 84.

ignore the records of a later state of things. Before we read the old palimpsest we must clear away all traces of the modern inscription."

Former intercontinental Regions

To cite an example in which a revision of the argument for permanency would be necessary, a region may be selected which the writer has found some opportunity to examine. At many localities in Malta, Sicily, and upon the peninsula of Italy, even as far north as the Alps, there are found the abundant remains of a typically African fauna, which includes elephants, hippopotamuses, hyenas, etcetera, forms which lived and died in intimate association with a fauna like that of southern Europe today. A study of this region affords evidence in the structure of its shores that the continental bridge which once joined southern Europe to Africa was destroyed in late Tertiary time through the depression of its greater portion to depths ranging from 3,000 to 12,000 feet below the present surface of the Mediterranean, leaving only the present peninsulas and islands as remnants. That this movement is not yet completed the frequent and disastrous earthquakes of the region may indicate.

A second striking illustration of the importance of zoogeographic studies interpreted in the light of organic evolution is furnished by Scott's* investigations of the specimens collected in Patagonia by the late Professor Hatcher. The presence there in Tertiary time of a definite fauna of the Australian and Tasmanian types is thus proven, and shows clearly that a land connection between South America and Australia must have existed, though considerable ocean depths now separate the two continents.

Some of the other areas which zoogeographers have with more or less persistence asserted were in geologically recent times connected are:

1. North and South America through the "Antillean continent."

2. New Zealand and Australia, separated by depths of 6,000 to 12,000 feet, for which connection in Cretaceous time is indicated.

3. The Solomon islands and New Guinea, separated by depths of 2,400 to 3,000 feet, for which bridging in Tertiary times is indicated.

4. Madagascar and Africa, separated by depths of 6,000 feet and more almost throughout the 250 miles of breadth of the Mozambique channel, which was certainly bridged in Middle Tertiary time.

5. Madagascar and India, separated today by depths of 15,000 feet, probably bridged in Tertiary time, when with much probability they had also a continental connection with Australia as a part of the "Gondwana land" of Suess.

* W. B. Scott: Geological Magazine, vol. 7, December 4, 1900, pp. 470-471.

6. South Africa and eastern South America, separated by depths in excess of 10,000 feet.

These contentions of zoogeographers have been quite generally opposed by geologists, who, following the views of Lyell, have found the demands too great for their acceptance. The new science of comparative geology, however, of which Professor Suess is the distinguished founder and head, is now coming to the support of zoologist and botanist; so that it is now pertinent for geologists to inquire concerning those regions which have intimately related faunas or floras and are today separated by ocean barriers, how the geological formations and their disposition may be compared for the two shores, whether mountain ranges are abruptly terminated at the coasts, and whether there are other evidences of marginal faults or scarps on or near the coast.

Katzer, from studies in Brazil,* has shown the probability that in Middle Devonian time the greater part of the area of South America was occupied by a moderately deep sea inclosed between continents on the northeast (beginning in Guiana) and southwest, which latter may possibly have extended from western Chile and Patagonia westward over a part of the present Pacific ocean to south Georgia. This South Pacific continent has constantly increasing significance in post-Devonian time. To this view Mawson† has contributed by showing that the discontinuity of the great fold chains of the South Pacific island groups concentrically arranged about the Australian continent is chiefly to be ascribed to *Graben* faulting, in which the land areas have risen simultaneously with the sinking, to form the sea floor. Terraced coralliferous limestones are found at elevations of several hundred feet (620 feet in one instance) and the drop near the shore amounts to 3,000 feet.

Since Tertiary time it can be shown that Australia has been connected with many of the now isolated islands of the Indian ocean.‡

The connection of South America with Africa through Ascension, Saint Paul rocks, and Tristan da Cunha, Schwarz makes very probable by several lines of evidence, one of which is the discovery of rocks of continental type inclosed in the lavas of the volcanic islands.§

On the northern border of this Africo-Brazilian continent, within the

* Dr Friedrich Katzer: Grundzüge der Geologie des unteren Amazongebietes, Leipzig, 1903, pp. 1-296, map. See also review by Schuchert, Journ. Geol., vol. 14, 1906, pp. 722-746.

† D. Mawson: The geology of the New Hebrides. Proc. Linnæan Soc. New South Wales, vol. 30, pt. iii, 1905, pp. 400-484, pls. 14-29.

‡ Wallace: Geographical distribution of animals, vol. 2. The Australian region, pp. 387-485.

§ Ernest H. L. Schwarz: The former land connection of Africa and South America. Journal of Geology, vol. 14, 1906, pp. 81-90.

area of the intercontinental sea, we find Barbados, a small isolated block with deep-sea radiolarian ooze resting on sandstone, clay, and coal of Tertiary age and indicating a change of level since Tertiary time of about 6,000 feet.*

Symmetry about the North Atlantic

It is also quite recently that Suess has expressed the view that the North Atlantic was formed as the result of depression on lines of dislocation along its borders. His earlier studies on interrupted zones of folding† had shown that three great folded arcs may be traced from east to west across Europe, though they are now present in isolated fault-bounded remnants only (such, for example, as the Black forest, Vogesen, Thuringian forest, Morvan)—the Caledonian, Armorican, and Alpine arcs. These studies were in 1898 extended‡ so as to include the American as well as the European side of the Atlantic. It is shown that in Europe the Armorican folds and the Hebrides, composed of ancient crystalline rocks, appear to be but the eastern ends of much larger masses, and it is suggested that under the northern portion of the Atlantic ocean an Archean region is buried, and farther south a folded arc on which the Upper Carboniferous rests unconformably.

"It is a very remarkable fact that the east coast of North America actually corresponds to these assumptions. Here, with the exception of some possibly Caledonian stretches, there appear but two tectonic elements, and they possess essentially the properties characteristic of *d* (Armorican folds, *Ed.*) and *f* (Hebrides, *Ed.*). They are separated by the straits of Belle isle and the lower course of the Saint Lawrence.

"To the north lies the broad Laurentian Archean mass, the Canadian shield, which extends beneath the horizontal Paleozoic sediments of the Arctic-American archipelago, probably far toward the pole and reaching over also to Greenland.

"To the south of it, in the Rias coasts of Newfoundland, Nova Scotia, and New Brunswick, rises a folded range with discordantly transgressing Upper Carboniferous, which carries the marks of the western continuation of a great folded zone with the same clearness that in Europe the Armorican zone bears of an eastern end."

James Perrin Smith has called attention to the fact that in Cretaceous and Eocene time the Atlantic shore American fauna had many species,

* W. T. Blanford: Anniversary address of the President of the Geological Society of London. Quart. Jour. Geol. Soc., vol. 46, 1890, pp. 59-110.

† Ed. Suess: Ueber unterbrochene Gebirgsfaltung. Sitzungsb. d. k. Akad. d. Wiss. z. Wien, vol. 94, 1886, Abth. I, pp. 111-117.

‡ Ed. Suess: Ueber die Asymetrie der nördlichen Halbkugel, ibid., vol. 107, 1898, Abth. I, pp. 89-102.

and most of the genera were those of the West European Cretaceous beds, indicating inter-migration along a submerged near-shore shelf.*

The general conclusion reached by Suess is as follows:

"As regards the oft-discussed question of the permanence of the continents and the oceans, one perceives the following: Individual folded zones become broken and divided into horsts, and younger folds develop in the horsts. The position of the region of recession and transgression, as well as the arrangement of the surface tensions (which find expression in the axes of the folds) within the northern hemisphere, has in its main lines remained the same since Cambrian time—that is, from the existence of the oldest recognized traces of organic life down to the present day. A similar degree of permanence has not characterized the oceans. During this time through depression new oceans have been formed, whose succession in age is stamped in the transgressions. Other oceans have disappeared in part in consequence of the new depressions themselves, and in part through the pushing up of new zones of folding in accordance with the old plan.

"Thus the margins of the continents and oceans change in spite of the continuity of the plan of the leading lines."

Modern View of Bradysisms

Suess has long maintained that secular oscillations are not sufficient to explain the repeated emergences and submergences of the land. The negative movements are, in his view, in part due to the withdrawal of water from the shores to fill the abysses formed by the depression of sections of the sea floor, while the positive movements may be ascribed to the partial filling of the ocean basins by sediments.

The statement of Milne that the movements of the sea floor in connection with macroseisms are in general downward, while corresponding movements upon continental shores are upward, is supported by the geological evidence obtained through the study of the shorelines of the present day with the use of historical documents. The many works treating of such movements have been collected and critically examined by Issel in an important monograph.† Issel's map of the bradysisms of the entire globe shows that the greater number of the areas of depression now in progress are beneath the sea, while the areas of elevation are upon the land. In those small land areas where depression is going on (for example, in Italy) there is evidence that this movement was often preceded by an elevation. In Japan especially have these shore elevations been confirmed, and they appear to have been especially rapid. A questionnaire with this end in view was conducted there a few years since by Professors

* J. P. Smith: Principles of paleontologic correlation. Journal of Geology, vol. 8, 1900, pp. 673-697.

† Arturo Issel: Le oscillazioni lente del suolo o Bradisismi. Saggio di geologia storica. Atti della R. Universita di Genova, vol. 5, 1885, pp. 417, map.

Milne and Kikuchi.* Elevations as great as one inch per year seem to have been indicated, and the upward nature of the adjustment is abundantly proven by the elevated sea terraces with coral reefs,† shell borings in rocks, etcetera.

There seems to be an increasing tendency to regard secular changes of level as traceable to movements of the type which produce earthquakes—that is to say, they occur not continuously, but *per saltum.* Exact measurements have, however, not generally been made. The most valuable exact data thus far available have been derived from the repetition of trigonometrical surveys as soon as possible after a great earthquake. At the time of the great Sumatra earthquake of 1892 a trigonometrical survey was in progress, and a relocation of stations showed that actual changes of position and elevation had occurred.‡ Much greater changes, as regards both position and altitude, were determined to have occurred during the great Indian earthquake of 1897, the relative changes of altitude between stations being here as great as 24 feet and those of location not less than 12 feet.§ Observations of a like character have been made in connection with the earthquake of Saloniki in 1902.‖ The suggestion of Issel that signals be established along the coast of Italy for the measurement of bradysisms has been taken up by Grablowitz on the island of Ischia. To extend the studies inland from the coast, Antonelli has utilized with success a regular observation of the expanse of sea visible below the horizon from a distant inland point, measuring the changes in altitude against an intermediate building.¶ That such a method could be made available was known from the fact that certain villages in the Jura which had been invisible 30 years before had come gradually into view, the roofs first appearing and afterward a portion of the walls.** Examples of a like nature have been given from Spain, Italy, Austria, and Columbia, S. A.†† The proposition has recently been made to em-

* John Milne: Movements of the earth's crust, etc. The Geographical Journal, 1896, pp. 1-27.

† Yoshiwara.

‡ J. J. A. Müller: Ueber die Verschiebung einer triangulationsfeiler in der Residenz Tapanuli (Sumatra) in folge des Erdbebens vom 17 Mai, 1892. Reviewed from Dutch sources in Pet. Mitth., vol. 41, 1895, pp. 97-98.

§ R. D. Oldham: Report on the great earthquake of 12th June, 1897. Mem. Geol. Surv. India, vol. 29, 1899, pp. xxx and 379, 44 pls.

‖ Rud. Hoernes: Das Erdbeben von Saloniki am 5ten Juli, 1902, und der Zusammenhang der makedonischen Beben mit den tektonischen Vorgängen in der Rhodopemasse, Mitth. d. Erdb.-Kom. d. k. Akad. d. Wiss. z. Wien, N. F.

¶ G. Antonelli: Bradisismi di una parte della costa adriatica. Boll. della Soc. Geol. Ital., vol. 9, 1890, pp. 119-131.

** Girardot: Notes sur les movements du sol qui se produisent actuellement dans le Jura. Mem. de le soc. d'emul. du Doubs, 1881.

†† Issel: Loc. cit., pp. 46, 105, 212, 258, 273, 354.

ploy photography to record such movements.* After the selection of a station with widely extended view (if possible, where several mountain ranges are visible at successively greater distances), photographs are to be taken with powerful telephoto-lenses at fairly regular and frequent intervals and under as nearly as possible the same atmospheric conditions. Such records, if made at a sufficiently large number of stations, can hardly fail to give a decisive answer to the question whether the so-called secular movements are in general continuous and regular or spasmodic and occasional; and, if the latter, whether the time of the change corresponds to local felt earthquakes or to periods of earth rumbling unaccompanied by sensible movement.

The Ocean Basins of the Secondary Era

A great contribution to our knowledge of ocean basins has been made by Haug, who, by bringing together the data of zoologists and botanists and placing them in relation to the results obtained by stratigraphic geologists, has shown that the great zone of geosynclinals—the belts within which the geological record is most nearly complete for the Secondary era, and which must therefore have then constituted the almost continuous sea-basin—these geosynclinals bound the zoogeographic and botanogeographic provinces of pre-Tertiary time.† Suess showed long ago‡ that the faunas of the geosynclinals have more generally a pelagic character.

The recent study of earthquakes has shed new light from more than one direction upon the problem of ocean basins. By the study of a lifetime the Count de Montessus has been able to show through a process of standardization and correlation that practically all the recorded earthquakes of the land areas (about 170,000 in number) have been localized within two great-circle belts of the globe, and that these belts correspond in position to the geosynclinals as they had already been mapped by Haug.§ These belts are today the highest regions and bordered by the steepest slopes on the land; and, though the continuous or nearly continuous low depressions of the Secondary era, they became the mountains of the era which followed. They are thus regions which have been most mobile during and since the Tertiary, and their present importance

* G. Agamennone: Determination des bradysismes dans l'interieur des continents au moyen de la photographie. Bull. de la soc. belge de geologie, vol. 18, 1904, pp. 20-38.

† Émile Haug: Les géosynclinaux et les aires continentales. Bull. Soc. Géol. France, 3d ser., vol. 28, 1900, pp. 617-711. See also Jour. Geol., vol. 15, 1907, pp. 294-297.

‡ Ed. Suess: Entstehung der Alpen, 1875, p. 98.

§ Loc. cit., p. 633.

as earthquake regions indicate that the cycle of change is uncompleted. This revelation, that the Tertiary was for later geological history not only the unique period for mountain birth and growth and for lava extravasation, but also for the formation of new ocean basins as well, has shown that some sort of balance was maintained between areas elevated in one part of the globe and those depressed in another.

Distribution of Seaquakes and Tsunamis

A noteworthy contribution to our knowledge of the ocean basins is to be found in the comprehensive study by Rudolph* from direct observations of seaquakes, submarine volcanic eruptions, and "tidal waves."† After search in earthquake catalogues, nautical magazines, ships' logs, etcetera, he has described and charted the observations of mariners regarding the quakings experienced upon vessels and likewise the undersea eruptions. These data from untrained observers are surprisingly accordant, which speaks for their general correctness. It is learned, and this is an observation of the greatest value, that the sensible shake from a submarine quake is soon lost in transmission through the sea, as is clearly shown by the fact that of two ships an angular degree apart one has received a very violent shock, though it has passed the other unnoticed. This observation, confirmed by the study of the explosions of submarine mines, gives great value to the observations, which are definitely located in position by the ships' logs. In a number of instances the alignment of shaken vessels has been apparent, as in the seaquake of December 22, 1884, which was located near the Azores.

Regarding the origin of under-sea disturbances Rudolph says:

"Movements of the individual parts of a fault cleft upon each other, be it in vertical or horizontal direction, are inconceivable without shaking of the orographic blocks (*Schollen*). It is a peculiarity of these tectonic earthquakes (one may call them dislocation or structure quakes, or, if you will, he may still further distinguish *Blatt* and *Wechsel* quakes) that with slight lateral extension of the shaken plane they are transmitted in a definite direction coinciding with the cleft" (p. 277).

The map of the globe on which Rudolph has charted his results‡ shows a confirmation of the correctness of the map of macroseismic origins by Milne on the one hand and with de Montessus's map of the regions of high seismicity on the other. The *tsunamis* as charted by Rudolph fringe

* E. Rudolph: Ueber submarine Erdbeben und Eruptionen. Beiträge z. Geophysik, vol. 1, 1887, pp. 133-365, pls. iv-vii; vol. 2, 1895, pp. 537-666; vol. 3, 1898, pp. 273-336.

† We shall adopt the excellent Japanese term *tsunamis* for these earthquake waves so generally and erroneously denominated tidal waves.

‡ Loc. cit., vol. 1, pl. vii.

the coasts of the areas of seismicity, as may be seen by comparing plates 1 to 3 in de Montessus's latest work.*

As regards the distribution of seaquakes, Rudolph has thus summarized his conclusions for the Atlantic, which has naturally supplied the most ample data:

"1. Submarine earthquakes and eruptions occur in all depths, in the shallow as well as the deep sea, on the submarine plateaus, and in the true depressed areas.

"2. The frequency and intensity in the manifestation of the seismic and eruptive forces are not dependent upon the distance from active or extinct volcanoes.

"3. There are habitual regions of shocks and portions of the sea quite free from them; with exception of these regions seaquakes occur also isolated and scattered over the ocean."

There are two most marked zones of seismicity in the Atlantic. One of these extends westward along the parallel from the mouth of the Tagus, thus continuing the Mediterranean zone and including Madeira and the Azores. The other is centered on the equator and continues the northern shore of the gulf of Guinea toward cape Saint Roque. Along the last-mentioned zone in particular the isobaths or submerged contours are sharply offset and the sea-floor presents precipitous slopes.

Only one wide area has appeared to be immune from seaquakes—the North Atlantic basin and its eastward extension in the trough to the west of the Azores. It is interesting to note that the northern of the two zones of high seismicity within the Atlantic corresponds to a central band of Milne's oval (H), which is located to the west of the European shore. The other area has, however, not been indicated upon the map of macroseismic ovals. These studies of Rudolph show that movement is today taking place on the steep slopes bordering the ocean deeps.

Having in mind the valuable generalization of de Montessus that areas of high seismicity are in correspondence with the geosynclinals, a suggestion is here afforded for their extension across the seas, upon which areas no data have hitherto been available.

Fractures of under-sea Cables at Time of Earthquakes

There is at least one other promising field to exploit for the more definite determination of zones of seismicity within the under-sea regions—the collation of the records of interruptions in telegraphic cables. Milne has already accomplished something in this line† and shown how valuable

* Les tremblements de terre, Paris, 1906.

† John Milne: Sub-oceanic changes. The Geographical Journal, London, vol. 10, 1897, pp. 129-146, 259-289.

such records are to seismology. Cables are found to have been repeatedly interrupted at the same points, and since in many districts they run in nearly parallel lines, the opportunity is afforded of locating with some definiteness the zone of displacement whenever the interruptions may be traced to this source.* Thus on October 4, 1884, three transatlantic cables were interrupted simultaneously at the base of the steep eastern slope of the continental shelf (Flemish cap) 330 miles from Saint John, New Brunswick. The cables run in parallel lines 10 miles apart and the fractured places lay opposite each other in a straight line,† probably indicating the considerable differential movement on the scarp. These and other cables have been repeatedly fractured at the same point. Thus the cable from Lipari to Milazzo, Sicily, has been five times interrupted at the same point, sometimes during known earthquakes, as during the great Calabrian earthquake of September 8, 1905. The other interruptions occurred November 21 and 22, 1888, March 30, 1889, September 11, 1889 (all during activity of volcano 3 miles away), and February 9, 1893.‡ Cable companies have given out but little regarding the interruptions of their cables, which nearly always occur during shocks in near-lying territory. Enough is known to say that there is here a mine of valuable data on the behavior of the sea-floor at the time of earthquakes. Out of 245 breaks of cables discussed by Milne 87 occurred at times when instruments were in operation which would record "unfelt" earthquakes; 58 of the 87 interruptions occurred at or about the times when unfelt quakes were registered at European stations.

Forster's Observations on sudden Changes in the Mediterranean Floor

Much the most important observations that have yet been made directly upon sea-bottom changes are those of Mr Forster,§ the manager and electrician of the Eastern Cable Company at Zante, Greece. The fact that a large part of the Mediterranean floor in late Tertiary time constituted with the large islands a broad bridge connecting Europe to Africa;‖ the complex fault system present in both the Italian and Balkan peninsulas;

* To note how large a part of the sea-floor is now crossed by cables, see a new map of the cable lines of the world (ownership given), which has recently been issued from the Geographical Institute of C. Opitz, Leipzig, published in the Deutsche Illustrirte Zeitung of March 1, 1906.

† Milne: Loc. cit., p. 262.

‡ W. H. Hobbs: Notes on a trip to the Lipari islands. Trans. Wis. Acad. Sci., vol. 9, 1893, p. 664.

§ W. G. Forster: Seismology, London, 1887, pp. 68. Reviewed by R. D. Salisbury in American Geologist, vol. 3, 1889, pp. 182-188.

‖ See Wm. Herbert Hobbs: The geotectonic and geodynamic aspects of Calabria and northeastern Sicily. Gerland's Beiträge zur Geophysik, vol. 8, pp. 293-362, 10 pls.

the steep shorelines and the profound depths of the sea adjacent to them; the remarkably abrupt changes in depth of the sea-floor, and the numerous seaquakes, submarine eruptions, and earthquakes on the near shores—these conditions give to the field of Mr Forster's observations a very unusual importance.

On the Ligurian coast in the maritime Alps, Upper Eocene beds are found at an elevation of 9,000 feet and Pliocene deposits at an altitude of 1,800 feet. Study of the sea bottom near shore shows that at the end of Pliocene or beginning of Quaternary time there was an elevation of nearly 5,000 feet, and that subsequently there has been a depression of the sea-floor comparatively near shore of about 3,000 feet. Recent movement of the same nature is shown not only by the earthquakes, but by verifiable changes of level.

The facts which Forster has gleaned by a long experience are striking enough, and they indicate that the geological changes which have been observed upon the land areas at the time of earthquakes are relatively small when compared to those which occur upon the sea-floor along such great scarps as his soundings have there discovered. Some of these precipices are from 3,000 to 5,000 feet high. Between the bow and stem soundings of the repair ship differences of 2,000 feet were measured. At the moment of the earthquake of October 26, 1873, the cable to the mainland broke 7 miles from the Zante office, and was firmly jammed under fallen material in a depth of 2,000 feet of water where formerly there had been 1,400 feet. In 1878, in connection with the violent earthquake across the Adriatic in Messina, which was felt slightly in Zante, the cable to Canea (Crete) was broken in two places 139 and 99 knots from the Cretan end, and so uneven had the floor become between these breaks that it was necessary to make a detour in laying the repaired cable. The earthquake of March 28, 1885, again injured this Crete-Zante cable, this time outside Sapienza, where the floor is extremely irregular and drops off quickly from 700 to 10,000 feet. In this instance the cable was jammed under a mass of material which had apparently been shaken from this cliff.

Another of Forster's interesting observations relates to the earthquake of August 15, 1886. In this instance the line from Zante to Crete was in use for a message at the time the shocks frightened the operator from the office, but only a few moments afterward the testing apparatus was adjusted and a dead break in the cable was located 23 miles from Zante. On grappling for the broken cable the repair ship found that the bottom suddenly increased in depth to the south of the break from 4,500 to 5,800 feet. A break occurred in the Zante-Corfu cable during the earth-

quake of December 7, 1885, where it lay in only 300 feet of water and only 1 mile off the Zante shore. With a sea telescope the smooth limestone bottom could be seen, with the line of the former position of the cable marked on it; but this was now 2 feet away, and the cable was found *actually lifted off the bottom.* Exactly where the cable had lain at one point there was a deep hole in the limestone, with radiating fractures presenting the "appearance a large pane of glass has when fractured."*

At the time of the great Ligurian earthquake of February 23, 1887, no faults appeared on the land, but several vessels a few miles off the coast received shocks so severe that it was at first thought they had struck bottom. During the following days a large number of deep-sea fishes, including *Alepocephalus rostratus,* were found dead in the shallow water along the Riviera or were stranded on the beach, especially in the neighborhood of Nice.† The earthquake at Kingston, Jamaica, January 14, 1907, was acocmpanied by a sinking of the harbor bottom by as much as 27 feet, and step faults upon the neighboring shore recorded an additional drop of 24 feet, making 53 feet as the total depression of the harbor bottom.‡

Contrast of Movements of crustal Blocks within the continental and under-sea Areas

The data above given not only reveal the possibilities of investigation along these lines, but, as already stated, they seem clearly to show that the changes in the configuration of the sea bottom by seaquakes are on a much grander scale than those with which we are now becoming familiar upon the land.§ To produce the seismic *tsunamis* such as those which inundate the eastern shore of Japan, and still more those larger waves which are registered by tidal gauges over the entire globe, it is necessary

* This description recalls the fractures radiating from a point, so familiar from the description and cut of the fissures found at Gerocarne during the Calabrian earthquake of 1783.

† Charles Davison: A study of recent earthquakes. London, 1905, pp. 162-163.

‡ Charles W. Brown: The Jamaica earthquake, Pop. Sci. Month., vol. 70, 1907, p. 401.

§ The largest displacements of earth blocks yet demonstrated on the land were in connection with the Iceland earthquake of February, 1875, when the depression of Sveinagja sank between faults 47 to 65 feet (F. de Montessus de Ballore, Les tremblements de terre, Paris, 1906, p. 110), and in Alaska, at the time of the earthquake of September, 1899, when the shores of Yakutat bay rose in places 47 feet above the sea-level (Tarr and Martin, Bull. Geol. Soc. Am., vol. 17, 1906, pp. 29-64, pls. 12-23). Surface faults have been produced of 33 feet throw in connection with the Assam (Indian) earthquake of 1897 (Oldham, Mem. Geol. Surv. India, vol. 29, 1899, pp. xxx and 379, 44 pls.). Displacements of the same order of magnitude occurred in connection with the earthquakes of India in 1818 (20 feet 6 inches), Sonora in 1872 (20 feet), and Owens valley in 1887 (20 feet).

to assume the movement of a mass of water of proportions truly astounding. The observations of Mr Forster have given us experimental data on a truly grand scale, and in connection with quakes at best of but secondary strength.

Modern Seismology and fundamental Conceptions of Geology

The earthquake cataclysms were in the days of the founder of uniformitarianism regarded as rare phenomena of the globe. The seats of the western civilization and culture were not then so connected by telegraph and cable with the earthquake zones of the globe as they are today, and conditions within those provinces could not be adequately judged. Of the known earthquakes at that time, moreover, much that was generally ascribed to the natural exaggeration inspired by terror we have now by investigation found to be literal truth. By natural inference the fundamental conception of modern geology, namely, that the present is the key to the past, came to mean much more than its mere words implied. It was interpreted to mean that geological phenomena were to be mainly explained by those forces only which in *countries of low seismicity* act so slowly that it is only by measurements extending over many years, or even centuries, that they can be detected. Almost infinitely slow warping of the crust, the forces of erosion, and vast periods of time—these elements loomed large in the concepts which were formed.

Modern seismology has now afforded us a measure of the amount of actual crustal movement which accompanies earthquakes of the first order of magnitude on the land. At the surface this measure generally lies between the limits for maximum vertical movement on a single plane of 10 and 60 feet—a movement which is begun and completed within a time more frequently measured in seconds than in minutes. The observations of Forster on the movements of the Mediterranean floor at the time of earthquakes, almost the only data of the kind yet available, as we have seen, indicate that the values above given for the amplitude of earth movements on the land are probably but a tithe of those which, on the floor of the ocean, accompany macroseisms. Yet of seisms capable of producing movements of this order about 70 occur each year.

The most impressive are, however, not necessarily the most important phenomena, and we must take full account of the fact that, according to Milne's estimates, 30,000 lighter shocks occur each year on the land areas each of extent and intensity sufficient at least to be appreciated by a considerable number of people. Of the number of such shocks on the sea-

floor we have as yet no means of judging, but it is probable that the number stands in some such relation to those determined for the land areas as do the grander seaquakes to the great land earthquakes. All the tendency of recent study has been, moreover, to show that the so-called bradysisms or slow movements of crustal elevation or depression take place not gradually, but *per saltum,* and differ in no essential particular save that of amplitude from the movements which are accompanied by earthquakes.

The bearing of these revelations from recent earthquake study has thus been to show that the formation of the present ocean basins in Tertiary and later times is not only easily conceivable, but, from the data furnished by seismology alone, extremely probable. The great Tertiary mountain ranges are still pushing up their heads, and the extensive studies brought together by Issel* on the basis of historical documents and observed measurements show that most of the seacoasts are today rising. Direct data for the continued sinking of the deeps of the ocean floor are naturally difficult to secure, but, so far as measurements have been made at the time of seaquakes, they indicate the main movement to be a downward one.

Crustal Block Movements within the Coral Seas

With a view to contributing to the solution of this interesting problem, the writer has brought into correlation some studies from within the belt of the earth's coral seas. As all are aware, the theory of Darwin explains the formation of atolls and barrier reefs through the depression of portions of the sea-floor, the reef of dead coral being continuously built up about mountain crests within the upper 150 feet of the sea while the floor is descending and submerging the mountains themselves. The later theory of Murray, it has been urged with much force, owes much of the support which it has secured in some quarters to the reluctance of geologists to accept such grand movements of the crust as are required by Darwin and his follower, Dana.

As Darwin pointed out, fringing reefs are an indication either of a stationary condition or of local crustal elevation. Throughout large areas of the coral seas later studies have confirmed this view, and we have today the numerous accounts by scientific travelers which furnish in many instances the actual present elevations of the raised coral reefs.

With the assistance of Mr Walter F. Hunt, instructor in mineralogy at the University of Michigan, the writer has brought together upon a map (plate 5) the data from these sources, as well as those for submergence based upon the location of atolls and barrier reefs. The results

* Loc. cit.

MAP SHOWING CHANGES OF LEVEL WITHIN AN AREA OF THE CORAL SEA

appear to reveal a relation both to the belts of earthquakes and to the zones of geosynclinals as these have been mapped by de Montessus and Haug respectively. We may thus add to the correspondencies already mentioned that of an actual record of recent differential vertical movement of crustal blocks within the earthquake zones, at least for the areas of the coral seas.

The elevations since the Tertiary, which are given in figures on the map, indicate not uniform values throughout any considerable area, but each island group or individual island shows an elevation which generally differs widely and quite erratically from that of its nearer neighbors, thus confirming the view of Mawson* that the groups are here separated by so-called Graben depressions.

The bearing of the facts above brought in review is to show that the ocean basins of the present day have been formed largely as a result of sinking of great orographic blocks bounded by submerged scarps which are even today the seat of progressive movement.

Isostatic Adjustment

As regards the coastlines of the continents, the resultant movement which has been going on since the Tertiary is, as has been already said, quite generally an upward one; but where large rivers are depositing their burden of sediment, a local settling is quite generally now to be noted. The way in which isostatic adjustment may locally modify the general vertical movement of the crust which takes place in relatively large masses McGee has well expressed in his study of the gulf of Mexico as a measure of isostacy.† Speaking of the greater movements of the crust, he said:

> "Now in contrasting these great oscillations with the gentle modern movement of the crust, they are found to differ widely; the modern subsidence is a gentle warping in such a direction as to deepen the basin and gradually submerge its perimeter, while the old oscillations were widespread and involved both sea bottom and continent. The modern movement is slight and commensurate with the simple and uniform processes of erosion and sedimentation, while the old movements were cataclysmic and utterly transcended the influence of rain and rivers."

Great oceanic Revolutions and geological Periods

The unique importance which for later geological time the close of the Tertiary acquires by reason of its having so profoundly changed the face

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* D. Mawson: The geology of the New Hebrides. Proc. Linnæan Soc. New South Wales, vol. 30, pt. iii, 1905, pp. 400-484, pls. 14-29.

† Bull. Geol. Soc. Am., vol. 3, 1892, pp. 501-503.

of the earth naturally suggests the great revolutions which occurred in the Permian and Algonkian times. It is noteworthy that each of the three periods appears to have been followed closely by a more or less extended continental glaciation, the Permian in "Gondwana land" and Brazil, the Algonkian in China, South Africa, and Ontario. The changes in extent and in depth of the ocean basins and the elevation of plateaus and mountain barriers react on climate through affecting the humidity of the atmosphere, through regulating the amount, character, and distribution of precipitation, and through changes in the ocean currents, thus offering at least a possible explanation of the glaciations.

In conclusion, it may be pointed out that there is in modern geological thought a tendency for the pendulum to swing backward to complete its cycle by returning toward the position which it had before the promulgation of the well known doctrines of Lyell.

FIGURE 1.—CAVE SANDSTONE LEFT BARE BY EROSION OF THE INCLOSING LIMESTONE

FIGURE 2.—CAVE SANDSTONE LEFT BARE BY EROSION

CAVE SANDSTONE

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CAVE-SANDSTONE DEPOSITS OF THE SOUTHERN OZARKS*

BY A. H. PURDUE

(*Read before the Society December 28, 1906*)

CONTENTS

Stratigraphy of the southern Ozarks

The surface rocks of the southern Ozarks are of Ordovician, Silurian, Devonian, and Carboniferous ages. Those of Silurian age are absent over a large portion of the region, as a result of unconformities, and those of Carboniferous age are locally absent, as a result of erosion during the present erosion cycle.

In southern Missouri and northern Arkansas the streams have in many places cut far below the Carboniferous rocks, leaving the older rocks exposed on the hillsides. The rocks of Devonian age consist of a thin stratum of sandstone, or of sandstone and shale, and as those of Silurian age are usually absent, practically all the rocks exposed below those of Carboniferous age belong to the Ordovician.

Near the Arkansas-Missouri line the Ordovician rocks exposed along the sides of the rather deep ravines consist of manganesian limestone containing several beds that are more or less cherty and locally thin beds of ripple-marked sandstone. A few miles south of the Arkansas-Missouri line there appear at the top of the manganesian limestone two beds of sandstone with an intervening bed of limestone. These sandstones are

* Received by the Secretary of the Society March 29, 1907.

(at least tentatively) regarded by Mr E. O. Ulrich, of the U. S. Geological Survey, as the Lower and Upper Saint Peter, and he named the limestone Everton, from the town of Everton, Boone county, Arkansas.

Unconformity at the Top of the Everton Limestone

The Everton limestone overlaps the Lower Saint Peter to the north and is (at least locally) unconformable on the rocks below. At the top of the Everton limestone there is a pronounced unconformity, which is strikingly visible at all points where this formation outcrops on the hillsides. A typical one of these exposures is shown in the following figure:

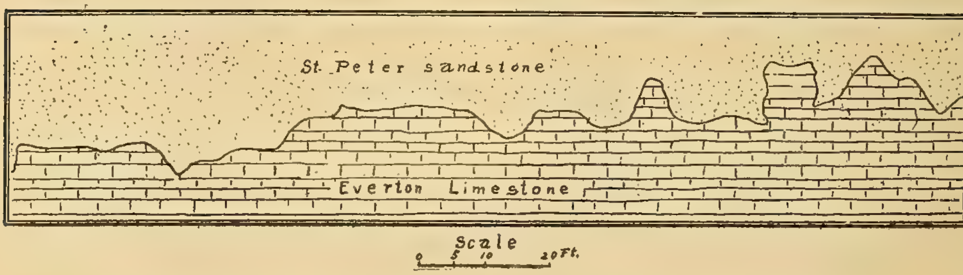


FIGURE 1.—*Unconformity at the Top of the Everton Limestone.*

From the nature of this unconformity there would seem no doubt but the irregular upper surface of the limestone is due to solution that took place at the base of the soil while this was the surface rock. In many places the limestone was dissolved out in wide basins a hundred feet or more in diameter, while in others the depressions were smaller and more cistern-like. As the sea advanced, the soil, which doubtless was mainly clay, was carried seaward and the Upper Saint Peter sandstone was put down on the very irregular but clean surface of the Everton limestone.

Sandstone Masses at the Horizon of the Unconformity

The sand filling these caverns is the last to succumb to weathering agents; so that in those parts where streams have cut down through the limestone there are on the hillsides, at the limestone level, numerous masses of sandstone, some large and bulky, others tall and slender, standing sentinel-like, as so many silent witnesses to geography of the past.

The Everton limestone is absent over western and the extreme northern part of Arkansas, but the unconformity that occurs at its upper part covers the whole area; so that sandstone masses like those described are present throughout the region. Those most convenient to be seen are in the vicinity of Eureka Springs, though they are larger and more numerous over the northern part of the Harrison quadrangle. Where the Everton

limestone is absent the sand forming the masses was deposited in basins in the Ordovician magnesian limestone at a somewhat lower horizon. In many places these sandstone masses have been thoroughly protected from erosion by the walls of the basin in which they lie and are covered over by the rocks of later age, the Sylamore sandstone, which is of Devonian

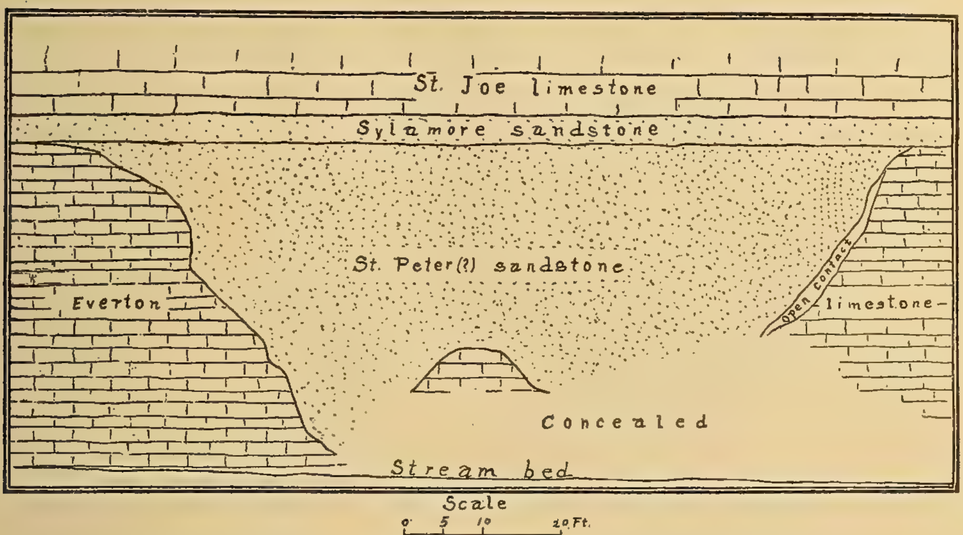


FIGURE 2.—*Pocket of Saint Peter Sandstone covered with Sylamore Sandstone.*

age, or the Saint Joe marble, which is Carboniferous. These two sandstones are quite similar, and it sometimes requires close observation to distinguish between them. A case of this kind is shown in figure 2.

Sandstone Masses in the manganesian Limestone

The sandstone masses occurring at the horizon of those mentioned above, while striking to the layman and interesting to the geologist, are easy of interpretation; but there are numerous others, occurring at a lower horizon, whose origin is not so evident. These masses have a general distribution over northern Arkansas and have been observed by the writer in the extreme southern part of Missouri. Those that are the subject of this paper are confined to no definite horizon, but are liable to be found anywhere in the upper hundred feet or more of the Ordovician dolomites. They vary in size from a few feet to fully 60 feet in height. In some cases they stand up alone on the hillsides, having been uncovered by erosion, and in other cases they are exposed in bluffs, surrounded by limestone. The limestone beds usually abut abruptly against the sandstone masses.

Shape and size of Sandstone Masses

In shape these sandstone masses vary from those of about equal dimensions in all directions to those whose length is much greater than their thickness. In some cases a mass will stand alone on the hillsides, and in other cases several occur closely associated, but usually at different levels. Frequently they are arched at the base when the material beneath is usually weathered out, sometimes leaving a cavern large enough to protect stock during stormy weather. This basal arching is so common as to almost be a characteristic of the masses (see figures 1 and 2, plate 6).

Character of the Sandstone

The sandstone composing the masses is saccharoidal and to all appearance is the same as the Saint Peter of this region. It is made up of medium sized, well rounded grains, so loosely bound together that frequently they crumble in the fingers. Beneath the blows of the hammer it is so friable that securing a hand specimen is a difficult matter. It is always of the same nature in the different masses and uniform throughout the same mass. No argillaceous material occurs in it. No stratification planes are visible, but often there are poorly developed cleavage planes standing perpendicular or at a high angle. Angular fragments of chert like that in the surrounding limestone are common in the sandstone, as also are blocks of angular limestone. These limestone blocks often are so large as to make it impossible for them to have been deposited by water. Careful search for conglomeratic material in the sand never revealed any that I could be confident was such. Loose material like that found on the floors of the caves may sometimes be seen beneath the sand, and in one case old stalagmitic material was found. In another case several feet of the outer surface of one of the masses were distinctly slickensided, the markings being vertical. In this case the inclosing limestone was very slightly arched beneath the sandstone mass, but the slight folding could not have caused the slickensides. There was no faulting of the inclosing limestone. In some cases the surface of the sand is weathered so as to give it a distinctly mammillary appearance—a thing which the writer does not attempt to explain.

Reasons for considering the Sand Masses Cave Deposits

The reasons for considering the sand masses cave deposits seem to the writer to be conclusive and are as follows:

1. The abrupt manner in which the limestone beds usually abut against the sandstone masses.

2. The shape and size of the mass is such as would be expected in the filling of limestone caverns.

3. The masses often occur one above the other, more or less perfectly separated by limestone beds, which is the arrangement frequently to be expected in limestone caverns.

4. The masses occur at no definite horizon, as would be the case had they been deposited contemporaneously with the inclosing limestone.

5. The writer explains the frequent occurrence of chert fragments and limestone blocks in the sandstone only on the supposition that they fell in from the roofs and sides of the caves while the sand was being deposited.

6. The absence of all stratification in the sand masses.

7. The presence, in one observed case, of stalagmitic material beneath the sandstone.

Source and Manner of Introduction of the Sand

The source of and manner of introduction of the sand into the caverns is one of the difficult things to determine in connection with the deposits. This is the more difficult because of the uniform cleanness of the sand. As stated, it contains no argillaceous material. How is the absence of this material to be accounted for? There would seem no escape from the conclusion that the sand, if introduced from the surface of the land area, would have clay mixed with it. Surface streams entering caverns would carry all the material, both coarse and fine, that they could get hold of, and this would be sorted to a greater or less extent. The cavern filling would not be different from the material deposited in the beds of streams, though stratification might not be so perfect.

If, however, we conceive of the sea advancing upon the land area, the material, both coarse and fine, comprising the soil would be picked up by the advancing waves, assorted, the fine carried seaward and the coarse deposited along the shore. With the advance of the sea, the rocks would be swept clean of soil, and if they contained caverns, these would be opened up to the floor of the sea, permitting the free ingress of the sand.

Features of the Sandstone accounted for

The one pronounced observed case of slickensides probably was produced by the settling down of the sandstone mass, most likely as a result of solution beneath. The common occurrence of vertical or nearly vertical cleavage planes probably is to be explained in the same way.

The absence of stratification finds its explanation in the uniform nature of the material and the probable constant rate of introduction. The quiet water in the caverns would prevent the formation of false bedding and ripple-marks.

In cases where the underground water passages leading from the caverns were short, open, and straight, the loose material that had accumulated on the floor of the caverns would, at least in large part, be removed by the ebb and flow of the tide, as the shoreline advanced on the land; but in those cases where such passages were long, small, and crooked the effect of the tidal surge would largely be destroyed and the loose material would remain in the floor of the cavern.

The arches so common at the base of the sandstone masses are in part explained by the weathering out of this loose material, and in part by the uneven floor of the caverns, as a result of differential solution.

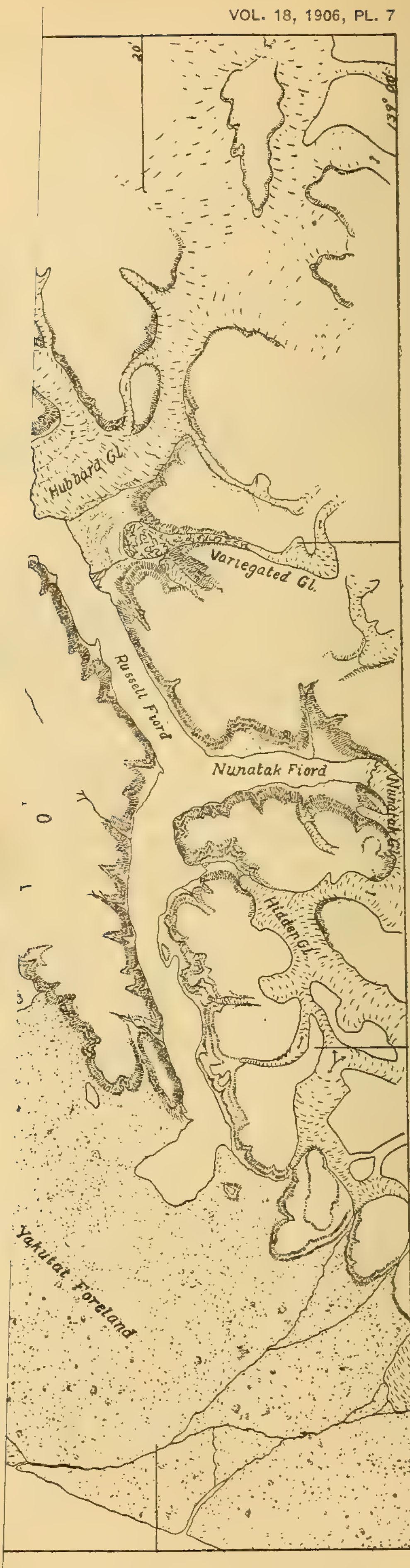
Age of the Deposits

The very close similarity between the sandstone masses occurring at the horizon of the Everton limestone and those occurring below, in the Ordovician dolomites, points to a common age of the two. It is the writer's belief that the caverns were filled at the same time the Upper Saint Peter sandstone was put down, and from the same material.

Age of the Caverns

The caverns probably were formed in part, at least, during the time of elevation that immediately preceded the deposition of the Upper Saint Peter sandstone, though their beginning may antedate this time; but while solution was going on over the Everton limestone, producing the very uneven surface and probably removing a portion of its outer border, the caverns were being formed in the manganesian limestone below.

When the conclusion here presented of the origin of the sand masses was forced on the writer by his own observations and in the face of preconceived ideas, it was difficult to account for an underground circulation of water sufficiently active to form the caverns at the time named; for while the surface of the Ordovician limestone in which the deposits occur is one of unconformity, it is surprisingly even, indicating that the region stood only a short distance above sealevel; but an even surface is the one, other things being equal, that is most conducive to a large underground water circulation. The amount of underground water may be sufficient to force a rather rapid circulation, even though the exit should be below sealevel; also the even surface is itself an evidence of such circulation, for without it surface drainage must have existed, which would have resulted in numerous valleys. Such valleys are only sparingly in evidence along the contact between the Ordovician limestone of the area and younger rocks laid down on them.



GION

is indicated by broken lines

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA

VOL. 18, PP. 257-286, PLS. 7-23 JUNE 15, 1907

RECENT ADVANCE OF GLACIERS IN THE YAKUTAT BAY REGION, ALASKA*

BY RALPH S. TARR

(Read before the Society December 28, 1906)

CONTENTS

* Published by permission of the Director of the United States Geological Survey. The work on which this paper is based was done in the summers of 1905 and 1906. I take this occasion to acknowledge the valuable assistance rendered in these two expeditions by my scientific associates, Messrs Lawrence Martin and B. S. Butler in 1905, and Messrs B. S. Butler, J. L. Rich, O. Von Engeln, and R. R. Powers in 1906.

Manuscript received by the Secretary of the Society March 4, 1907.

SKETCH MAP OF THE GLACIERS OF THE YAKUTAT BAY REGION

Based on the Alaska Boundary Tribunal map. The newly crevassed glacier is indicated by broken lines

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Introductory Statement

Since its discovery, the Malaspina glacier has been in a nearly stagnant condition around most of its periphery. As a result of ablation, in this outer portion of the glacier, there has developed a fringe of moraine-veneered ice, parts of which support forest growth. Back of this morainic fringe the ice plateau has been so smooth as to permit easy sledging in all directions by the several parties (the last in 1897) which have crossed it on their way to mount Saint Elias. Such was apparently its condition even as late as the summer of 1905; but in 1906 that part of the Malaspina glacier which borders Yakutat bay was transformed to a sea of crevasses, across which travel was utterly impossible. This crevassing has been caused by a great forward thrust, which has not only broken the ice surface, but has also pushed forward the glacier margin, and in the summer of 1906 was still pushing it forward.

The evidence is clear that the many smaller glaciers of the Yakutat Bay region were in a condition of general recession up till 1905; but between August, 1905, and June, 1906, three of them have undergone a remarkable advance, accompanied by profound crevassing. It is the purpose of this paper to describe these changes and to offer an interpretation of them.

Location and Topography of the Area studied

Yakutat bay is an indentation in an otherwise straight coastline about midway between Cross sound and Controller bay. Malaspina glacier bor-

ders the western shore of the outer bay, being fed by numerous tributaries from mount Saint Elias and neighboring mountains. The outer bay is V-shaped, narrowing toward its head, where it enters between mountain walls as a true fiord known as Disenchantment bay. The entire inlet has the shape of a bent arm, the elbow being at the point where the fiord reaches farthest into the mountains, the part beyond the elbow extending back toward the ocean in a course roughly parallel to the outer bay. The inlet above the elbow is called Russell fiord.

Near the shores of the fiord the mountains reach elevations of from 3,000 to 5,000 feet, but immediately back of these the Saint Elias chain rises to elevations of from 10,000 to 19,000 feet. Situated on a windward coast, these lofty mountains induce heavy precipitation, and are therefore deeply clothed with accumulations of snow at all elevations above two or three thousand feet. It is this great accumulation of snow which causes glaciers to descend nearly all the valleys.

Previous Work

In 1890 and 1891 Malaspina glacier was studied by Professor Russell, who crossed it along several lines, and from whose descriptions* we have obtained most of our present knowledge of this interesting ice-sheet. Professor Russell has also briefly described the other glaciers of the Yakutat Bay region. In 1897 both Prince Luigi, Duke of the Abruzzi, and Mr H. C. Bryant crossed Malaspina glacier from outer Yakutat bay to the mountain base.† As a member of the Harriman Alaska expedition Dr G. K. Gilbert studied the glaciers of Yakutat bay in 1899,‡ and presented evidence that there had been general recession since the earlier observations of Professor Russell. The photographs and maps of the Alaska Boundary Tribunal clearly show the condition of the glaciers in 1895. The studies of Tarr and Martin in 1905 prove that the recession of the glaciers continued up to that time.§

General Description of the Glaciers

MALASPINA GLACIER

A number of large valley glaciers (see plate 7), descending from the Saint Elias range, spread out at the mountain base to form the broad

* National Geographic Magazine, vol. 3, 1891, pp. 53-203; 13th Annual Report U. S. Geological Survey, 1891-2, pt. 2, Geology, pp. 1-91.

† Mr Bryant has published no description of his expedition; but the results of the Abruzzi expedition are described in a volume entitled "The ascent of mount Saint Elias, narrated by Filippo de Filippi," 1900.

‡ Harriman Alaska Expedition, vol. 3, "Glaciers and Glaciation," 1904, pp. 45-70.

§ Bull. American Geographical Society, vol. 38, 1906, pp. 145-167.

piedmont ice plateau known as the Malaspina glacier, which reaches the sea at two points—Icy cape on the west and Sitkagi bluffs on the east. Icebergs are discharged into the ocean from the former, but the latter is merely a moraine-veneered ice-cliff, against the base of which the ocean waves beat.

Each of the tributary glaciers dominates a part of the Malaspina ice plateau. The eastern portion is under the influence of Marvine glacier, which supplies the ice of that part of the Malaspina bordering Yakutat bay. The tributary next west of the Marvine is Seward glacier, and west of this is the Agassiz. East of the Marvine is the much smaller Hayden glacier, which, although completely joined to the Malaspina, produces little effect upon its ice supply, excepting in a very narrow strip along the eastern margin.

A bay in the ice is formed on the lee, or southern, side of the mountains where the Marvine and Hayden glaciers unite, and in this ice-free area a small hill rises, to which Russell applied the name Blossom island. A good-sized stream, supplied by the melting along the margin of the Marvine and several smaller glaciers, traverses this area, expanding into a lake, then escaping beneath Hayden glacier through a subglacial tunnel about 5 miles in length. On emerging from its tunnel, on the eastern margin of Malaspina glacier, this stream is known as Kwik river—a great, rushing, glacial torrent which flows to Yakutat bay in a course roughly parallel to the eastern margin of the Malaspina.

On his way to mount Saint Elias in 1890, Professor Russell crossed Hayden glacier, went across Blossom island, then traversed Marvine glacier. So far as known, his is the only expedition which has previously visited this portion of Malaspina glacier. In 1905 I did not reach this region, but we had clear views of it from neighboring mountains, and two of my party, Messrs Martin and Butler, looked down on it from the slopes on the western side of the Floral hills directly above Hayden glacier. Professor Russell found Marvine glacier easy to cross in 1890, and from our views of 1905 we are convinced that there would then have been no difficulty in crossing this part of Malaspina glacier; but in 1906, from far up the mountain valley north of Blossom island down to the very margin on the shores of Yakutat bay, a distance of not less than 15 miles, that part of the Malaspina dominated by Marvine glacier was so crevassed as to be utterly impassable.

LUCIA AND ATREVIDA GLACIERS

Lucia glacier lies just east of the Hayden, and adjoining the Lucia on the east is Atrevida glacier. In their lower portion these two glaciers

FIGURE 1.—VARIEGATED GLACIER, JUNE 22, 1899

Showing winding course, smooth surface, and moraine-covered terminal portion. Essentially as in 1905. Orange glacier on right. Photograph by G. K. Gilbert

FIGURE 2.—LONG-FOCUS PICTURE FROM SAME SITE AS FIGURE 1

Note crevassed condition down to interior flat. Photograph by O. Von Engeln, July 3, 1906

GENERAL VIEWS OF VARIEGATED GLACIER, 1905 AND 1906

coalesce and their terminus extends to within 1½ or 2 miles of Malaspina glacier, to which they were formerly tributary. At present the alluvial fan of Kwik river separates these glaciers from the Malaspina. In 1905 the lower portions of both Atrevida and Lucia glaciers were essentially stagnant, and from well within their mountain valleys to their terminus were covered with broad wastes of moraine. The outermost portion of the moraine-covered ice was clothed in a dense thicket of mature alder, indicating almost complete stagnation in that part of the glacier.

Russell crossed both these glaciers in 1890. In 1905 I walked freely over Atrevida glacier in company with Messrs Martin and Butler, and later they crossed Atrevida and Lucia glaciers on their way to Floral hills; but in 1906 crevassing, due to a rapid forward movement, had completely altered the condition of Atrevida glacier. The Lucia, on the other hand, was in no way different from its condition in 1905, at least along and near the route followed by Messrs Martin and Butler.

GLACIERS OF YAKUTAT BAY

Galiano glacier (plates 7 and 13), the next one east of the Atrevida, was the same in the two summers; but there is evidence of distinct change between 1890 and 1905.

Three tidal glaciers discharge into Yakutat Bay inlet. The outermost of these, Turner glacier, underwent no notable change in the interval between 1905 and 1906; but a small unnamed glacier just north of it, which I shall call Haenke glacier (plates 11 and 12), has advanced into the sea, uniting with the ice-cliff of the Turner. Hubbard glacier was essentially the same in 1906 as in 1905; but the much smaller Variegated glacier (plates 8–10), just east of it, shows profound change. The tidal Nunatak glacier, at the head of Nunatak fiord, continued to recede between 1905 and 1906, as it had been doing at such a remarkable rate between 1891 and 1905.* Another large glacier, the Hidden, whose terminus is on an alluvial fan back from the sea, shows no notable change. There are many smaller glaciers in the bay, and in none of these was any evidence of recent advance discovered.

This brief description makes it clear that four of the many glaciers in the Yakutat Bay region have been subjected to some influence which has caused a very remarkable change in condition in the short interval of ten months between August, 1905, and July, 1906. The nature of this

* Tarr and Martin: Bull. American Geographical Society, vol. 38, 1906, p. 154.

change will now be more definitely stated for each of the glaciers concerned.

The advancing Glaciers

VARIEGATED GLACIER

Condition in 1905.—Variegated glacier (plates 8–10), having its source far back in the mountains, descends in a serpentine course through a valley greatly steepened by glacial erosion (plate 8, figure 2). On emerging from its mountain valley, the glacier expands into a broad, bulb-shaped area which extends westward until it coalesces with Hubbard glacier, and southwestward almost to the sea.

In August, 1905, this glacier was studied with some care, especially in its bulb-shaped expansion outside of the mountain front, which presented some interesting morainic phenomena. We walked freely over the bulb-shaped terminus and ascended the valley glacier to a point 6 miles or more from the sea. At that time all parts of the glacier visited were easily traversed and possessed no areas of marked crevassing. In the middle of August the snowline on the glacier was at an elevation of approximately 2,200 feet. At and above snowline there was some crevassing, but not enough to impede travel as far up as we went. In this upper portion numerous small tributary glaciers descended by steep grades from hanging valleys.

Below snowline the glacier surface was rapidly melting, and toward the end of the mountain valley it was littered with angular rock fragments. Everywhere the surface was so smooth that one could travel in a straight course over it with almost no detours on account of crevasses (plate 9, figure 1). The slope of the valley portion of the glacier varied from 7 to 10 degrees, but flattened decidedly near the end of the mountain valley, where in places the grade was even reversed.

On emerging from this mountain valley Variegated glacier expanded abruptly and, through ablation, became covered with an almost continuous sheet of moraine. This morainic veneer varied in thickness, causing a succession of ridges and intermediate depressions arranged concentrically (plate 9). These concentric ridges, which roughly paralleled the bulb-shape of the expanded ice-foot, consisted of rocks of various kinds and colors, giving rise to a remarkable series of crescentic moraines whose characteristics we studied with some care. The outer portion of the expanded ice-foot, near the sea, was so stagnant and so deeply covered by moraine that scattered willows and alders were growing on it, and the

FIGURE 1.—INNER EDGE OF MORAINE-COVERED VARIEGATED GLACIER

Transformed in 1906 to sea of crevasses. Orange glacier on left. Photograph by Lawrence Martin, August 8, 1905

FIGURE 2.—MORAINE-COVERED PORTION OF VARIEGATED GLACIER

Transformed in 1906 to crevassed condition shown in plate 10, figure 2. Photograph by Lawrence Martin, August 8, 1905

VIEWS OF MORAINE-COVERED OUTER VARIEGATED GLACIER, 1905

underlying ice was only occasionally revealed. It was this stagnant outer portion which reached up to and coalesced with Hubbard glacier.

Within this outer stagnant area was a long crescent-shaped depression (plate 10) underlaid by ice, into which two glacial streams, emerging from the moraine-covered inner portion of Variegated glacier, poured their sediment, building up a broad flat through the coalescing of the alluvial fans. On emerging from the ice the larger, or southeastern, stream entered a canyon in the granite bed rock, and after a short course, interrupted by a notable waterfall, emerged from it at the head of its alluvial fan (plate 10, figure 1).

Inside of and concentric with this interior alluvial flat, the moraine-covered ice rose steeply in a succession of concentric ridges of variously colored moraines—red, orange, and purple. This inner portion of the glacier, although almost completely covered with moraine (plate 9, figure 2), was evidently more active than that part which lay outside the interior flat. Vegetation was represented only by occasional annual plants, and now and then by a willow a year or two old. The moraine was so thin that ice was frequently visible and could almost always be reached by thrusting the ice-ax into the moraine. There was no crevassing, and it was evident that this part of the glacier, like the portion within the mountain valley, was rapidly wasting. The inner edge of this moraine-covered area, lying almost at the very mouth of the mountain valley, was crescentic in outline and rose steeply and abruptly above the rapidly melting clear ice of the valley glacier (plate 9, figure 1).*

Condition in 1906.—The above description applies to Variegated glacier in the middle of August, 1905. When we again saw it, late in June, 1906, it was absolutely altered (compare figures 1 and 2, plate 8). The area of stagnant ice outside of the interior flat was unchanged. The flat itself was also essentially as it was in 1905, though slightly smaller; but all the ice to the northeast of the flat was broken into an impassable condition (plate 8, figure 2). In a period of ten months this glacier was altered from one over which we easily passed, making a journey of over 12 miles in a single day,† to one whose crevassed margin, even, we found it impossible to ascend without the laborious work of cutting steps in the ice.

Not only was the moraine-covered expansion, just outside of the mountain valley, broken into a labyrinth of crevasses, but this condition ex-

* For further description and illustration of this glacier, see Tarr and Martin, Bull. American Geographical Society, vol. 38, 1906, pp. 147-149.

† This refers merely to the distance in a straight line, for we made many side trips during this day.

tended at least as far up the valley as we had gone the previous summer, and from one side of the valley to the other. By the crevassing, the concentric moraines northeast of the interior flat were completely destroyed, the ridges being replaced by a uniform maze of jagged ice pinnacles. Some of the moraine still clung to the flatter portions of the broken ice, but most of it had tumbled into the crevasses. In consequence of these changes a large measure of clear ice appeared where, in 1905, only moraine was seen when viewed from a distance. Thus the appearance of the glacier was as totally altered as its condition.

In addition to this breaking, there has been a decided thickening of the lower portion of the advancing glacier, so that it now rises between 200 and 300 feet higher than it did in 1905 (compare figures 1 and 2, plate 10). The margin has also advanced seaward and encroached somewhat on the interior flat; but the advance has not disturbed the ice platform of the flat, nor of the moraine-covered area outside of it. Exactly how much of an advance there has been can not be stated, since we have no exact basis for measurement, though, so far as could be told from comparison of photographs, it seems to be certainly not less than 200 yards. The forward movement has caused the ice to override and bury the granite gorge which was visible in 1905 (plate 10), and the forward thrust has so completely destroyed the system of subglacial drainage that a stream no longer emerges from this part of the glacier. Instead, a large stream now issues from the eastern side of the glacier, descending through a marginal channel which in 1905 carried little, if any, water from Variegated glacier.

By this transfer in position of the glacial stream the rapid building up of deposits in the interior flat has stopped, and the stream emerging from it is greatly diminished in volume. On the other hand, a stream which in 1905 carried waters mainly from Orange glacier is now greatly increased in volume and rushes as a violent torrent through a marginal channel cut in the granite more than a quarter of a mile from its course in the previous summer. On emerging from this canyon the stream spreads out over a broad alluvial fan in a series of distributaries.

This fan, which is built out into Russell fiord, is very large, and in 1905 attracted our attention especially because glacial waters no longer occupied the eastern portion, on which, instead, there was a dense alder growth, with the individual bushes at least twenty-five years old. We interpreted this condition to be the result either of a diminution in volume of the glacial waters or of a transfer in their point of emergence. We little suspected, however, that in ten months this part of the fan

FIGURE 1.—INTERIOR FLAT AND INNER MORAINE-COVERED ICE FROM OUTER MORAINE-COVERED VARIEGATED GLACIER

Photograph by Lawrence Martin, August 8, 1905

FIGURE 2.—LONG-FOCUS PICTURE OF INTERIOR FLAT, AUGUST 17, 1906

Compare with Figure 1

VARIEGATED GLACIER 1905 AND 1906 FROM NEARLY SAME SITE

TURNER AND HAENKE (ON RIGHT) GLACIERS IN 1895

View is from Haenke island. Condition essentially same as in 1905. Photograph by Brabazon, of Canadian Boundary Commission

would again be occupied after an interval of freedom from deposit of over a quarter of a century.

By this change the heavily sediment-laden glacial stream is now coursing through the alder thicket in a multitude of branches which are rapidly killing and burying the bushes. That this change occurred late in the spring or early in the summer of 1906 is proved by the fact that all the alders are in full leaf. That the complete destruction of the alder thicket is imminent is evident from the fact that the roots of the plants are bathed in glacial waters, while the gravel deposit is rapidly rising above them. The summer of 1906 is probably the last season of life for these plants.

ORANGE GLACIER

East of the expanded ice-foot of Variegated glacier there is another glacier which heads on a low, flat divide from which the ice descends eastward toward Nunatak fiord and westward toward Variegated glacier. This, which I now call the Orange glacier (plates 8 and 9),* because of the presence on it of a pronounced orange-colored medial moraine, is a smooth, flat glacier with gentle grade and, so far as we could see, with no pronounced tributaries, its supply coming mainly from snowfall and snowslides in the flat divide area. Since the inclosing mountains are not lofty and the tributaries few and small, this glacier differs widely from the neighboring Variegated glacier. Although we did not go out on Orange glacier in 1905, we saw clearly all but its terminus; and are convinced that it was then in essentially the same condition as in 1906, when we made a journey out upon it nearly up to the snow-line.

Thus we have the anomaly of two neighboring glaciers, both of which were essentially uncrevassed and easily traversed in August, 1905, but one of which has so changed as to become impassable in a period of ten months, while the other shows no noticeable change. In fact, one of them, Variegated glacier, is so broken that attempts to ascend the margin to a point where we photographed it in 1905 were completely frustrated.

TURNER GLACIER

This glacier (plates 11 and 12) flows eastward from mount Cook through a valley more than a mile in width, and on passing out of its mountain valley expands to about double this width, ending in an ice-

* The name Variegated glacier was extended to this by Tarr and Martin in 1905, on the belief, which we shared with Russell and Gilbert, that it was continuous with the stagnant moraine-covered ice described above; but in 1906 we went out on it and found it almost completely separated from the stagnant ice-foot, which is really a part of the advancing Variegated glacier, as stated above. The name of 1905 is therefore inappropriate and is withdrawn.

cliff from which icebergs are discharged into Disenchantment bay. It is an actively moving and greatly crevassed glacier, and this has been its condition since first seen by Russell in 1890.

HAENKE GLACIER

Condition in 1905.—Not over half a mile north of the Turner there is a small glacier (plate 11), and about three-quarters of a mile farther north another similar one. These two glaciers have never been named. In 1905 they were so nearly alike that a description of one would practically apply to the other. Each descended rather steeply, at an angle of perhaps 15 or 20 degrees, and ended at the head of an alluvial fan about a quarter of a mile from the fiord. The lower mile of their course consisted of what appeared to be essentially stagnant ice, so veneered with black shale fragments as to completely hide the ice when viewed from a distance. Because of this blackness none of our photographs reveal the true glacier character of the lower ends, though it was evident enough to the eye. It is, however, clearly shown in a Boundary Commission photograph taken in 1895, from which it is evident that the condition was then identical with that in 1905.

Condition in 1906.—In June, 1906, the northern glacier had advanced somewhat and become slightly crevassed; but the southern, or Haenke glacier, had undergone a wonderful change (plate 12). It had not only advanced over its alluvial fan, but had moved boldly out into the fiord, expanding both to the north and south, in the latter direction coalescing with Turner glacier, and extending the ice-cliff of that glacier fully a mile to the northward. As a result of this forward advance, the front of Haenke glacier had by June, 1906, advanced not less than a mile farther out than it was ten months before.

As in the case of Variegated glacier, this forward rush has broken the ice into a sea of crevasses, from the ice-cliff in the fiord to a point at least as far up the mountain valley as we could see. Unlike Variegated glacier, this breaking of the ice has not been followed by a notable disappearance of the morainic veneer, and therefore its surface is still black with debris. This fact may be due to the recency of the advance, although in all probability it is chiefly the result of the difference in climate between this point and Variegated glacier. Lying as it does between the ice-cliffs of the Turner and Hubbard glaciers, and fronted by a continuous stream of floating ice, the climate of this part of the inlet is decidedly colder than other portions. In fact, in the first week of July snow still remained on the alluvial fan north of Haenke glacier. There

HAENKE GLACIER AND NORTHERN END OF TURNER GLACIER

View is from Haenke island, June 21, 1906. New ice cliff of advanced Haenke glacier on right. Contrast with plate 11. Long-focus photograph by O. Von Engeln

FIGURE 1.—GALIANO GLACIER, 1890

Dark part just outside mountain valley is alder growth on glacier. Photograph by I. C. Russell

FIGURE 2.—GALIANO GLACIER

From near same site as Figure 1, August 21, 1905. Note absence of alder, destruction of alluvial fan, and development of moraine on its site

GALIANO GLACIER, 1890 AND 1905

has therefore been little opportunity for ablation to lower the morainic debris into the recently formed crevasses of Haenke glacier.

If the advance which has pushed Haenke glacier out into Disenchantment bay should continue, and if the neighboring glaciers should share in it, it seems by no means improbable that the ice-cliff of Turner glacier might be united with that of Hubbard glacier. Such a paroxysmal thrust as has affected this small valley glacier, extended to the much greater Hubbard and Turner glaciers, might even result in again filling Disenchantment bay with glacier ice. This result would surely come about if these two great glaciers should receive a similar impulse proportional to their great size. Even as applied to this small Haenke glacier, the forward movement is astonishing; and although, owing to the uncertainty as to the cause and the nature of its effects, no prediction can be made as to the future, it is certainly within the realm of possibility that the next few years may witness some remarkable changes in the great tidal glaciers of Disenchantment bay.

GALIANO GLACIER

Condition in 1890.—In 1890 Professor Russell camped on the west side of Disenchantment bay, near the end of Galiano glacier (plate 13). He gives the following description of its terminus:*

> "To the north of our camp, and about a mile distant, rose a densely wooded hill about 300 feet high, with a curving outline, convex southward. This hill had excited my curiosity on first catching sight of the shore, and I decided to make it my first study. Its position at the mouth of a steep gorge in the hills beyond, down which a small glacier flowed, suggested that it might be an ancient moraine, deposited at a time when the ice-stream advanced farther than at present. My surprise therefore was great when, after forcing my way through the dense thickets, I reached the top of the hill, and found a large kettle-shaped depression, the sides of which were solid walls of ice fifty feet high. This showed at once that the supposed hill was really the extremity of a glacier, long dead and deeply buried beneath forest-covered débris. In the bottom of the kettle-like depression lay a pond of muddy water, and, as the ice-cliffs about the lakelet melted in the warm sunlight, miniature avalanches of ice and stones, mingled with sticks and bushes that had been undermined, frequently rattled down its sides and splashed into the waters below. Further examination revealed the fact that scores of such kettles are scattered over the surface of the buried glacier. This ice-stream is that designated the Galiano glacier on the accompanying map."

The photographs which Professor Russell took of Galiano glacier show clearly that its lower end was then completely covered with alder thicket

* National Geographic Magazine, vol. 3, 1891, p. 89.

(plate 13, figure 1). They moreover reveal the fact that there was an extensive alluvial fan southwest of the alder-covered glacier terminus.

Condition in 1905.—On our visit to this region in 1905 we were greatly surprised and puzzled* by the fact that Galiano glacier no longer supported an alder thicket (plate 13, figure 2). On investigation we found much wood scattered over the moraine-covered terminus of the glacier, and even battered stumps in place. We were further puzzled by the fact that the alluvial fan, which shows clearly in Russell's pictures, was no longer present (compare figures 1 and 2, plate 13). In its place there is much moraine, over certain portions of which wood fragments are scattered (plate 14), as if alder and cottonwood growth had been destroyed. The glacial streams now wind through this moraine in a multitude of channels, and their deposits are rapidly burying the morainic hummocks (plate 14). There is every appearance of having been an upward thrust through an alluvial fan, destroying it, throwing down vegetation wherever it grew, and leaving scattered morainic hummocks in place of the fan. The signs of this disturbance extend over a bulb-shaped area to a distance of 3 or 4 miles from the visible terminus of Galiano glacier.

The explanation of such a remarkable change seemed so difficult to us that in our preliminary report we did not discuss it fully. Nevertheless we were even then forced to the conclusion that between 1890 and 1905 there must have been a forward thrust of Galiano glacier which broke up a bulb-shaped expansion of the glacier that was buried beneath alluvial fan deposits of the glacial streams. We searched carefully for evidence of buried ice in this area, but found no definite proof of it, although from the larger areas of morainic hummocks there was far more water emerging, and with lower temperature, than could be accounted for by the normal run-off of rainfall. Moreover, there were numerous water-filled pits in the moraine, proving recent sinking, but none in which we could be positive that the settling was still in progress.

In the light of the observations of 1906 I am convinced that these changes are to be correlated with the changes which were observed in the other glaciers described in this paper, and that a few years ago the Galiano glacier was subjected to a forward thrust similar to that now affecting Variegated, Haenke, and Atrevida glaciers. The effect of this thrust has now died out and the glacier is returning to its normal condition, although as yet the alder has not again taken root on the moraine and the alluvial fans have not yet again buried the moraine of the out-

* Tarr and Martin: Bull. American Geographical Society, vol. 38, 1906, p. 152.

TOPOGRAPHY NEAR GALIANO GLACIER

View is from near same site as plate 13, looking in opposite direction. Note newly formed moraine hummocks, with alluvial fan developing among them, and tree fragments scattered about. Photograph by O. Von Engeln, 1906

FIGURE 1.—MORAINIC WASTE ON ATREVIDA GLACIER WITH A SINGLE CREVASSED AREA

View looking north from near middle of glacier. Photograph by Lawrence Martin, August 18, 1905

FIGURE 2.—SURFACE OF ATREVIDA GLACIER

Looking south from west margin. Site of figure 1 about in middle of picture. Photograph (long focus) by O. Von Engeln, August 2, 1906

ATREVIDA GLACIER SURFACE, 1905 AND 1906

lying, bulb-shaped terminus. If this is the true interpretation of the phenomenon, as it seems to be, we may expect that the other advancing glaciers will also soon cease their forward movement and return to their former state of stagnation.

There is a special reason why Galiano glacier might well have been early affected by the cause which is pushing these glaciers forward. It occupies a valley with steeply rising walls, from which the snow might easily be shaken down, and is so short that the effect of such an unusual accession of supply would quickly be transferred to the outer margin of the glacier (plate 13). A comparison of Russell's photographs with the conditions of 1905 shows clearly that there has actually been a great downfalling of snow and ice since his photograph was taken (compare figures 1 and 2, plate 13). Large areas of the steeply sloping mountains which were then covered with snow and ice are now bare rock.

ATREVIDA GLACIER

Condition in 1905.—The Atrevida glacier (plates 15–19) descends through a broad, steep-sided mountain valley, and on its emergence spreads out in a fan-shaped piedmont terminus. Where it emerges from its mountain valley it is somewhat more than a mile in width, but outside of the mountains it attains a width of not less than 3 miles.

In August, 1905, the lower part of this glacier was covered with a broad sheet of moraine, almost completely obscuring the ice, and extending from well within the mountain valley to the terminus of the glacier. On the outer portion of this moraine-covered ice there was a dense alder thicket, so obscuring the moraine that it was impossible from distant views to tell where the glacier ended.

At this time it was easily possible to travel over any part of the glacier excepting the alder-covered portion, where the dense growth of vegetation obstructed the way. With my party I looked down on the glacier from the mountains which rise directly above its eastern margin; later we made a trip out to the middle of the glacier; and still later Messrs Martin and Butler crossed it on their way to Blossom island, following the route which Russell took in 1890. At that time a mature spruce forest extended close up to the moraine-covered eastern edge of the ice, and a stream emerged from the extreme eastern margin through a tunnel which, so far as we could see, was exactly as it was when Russell photographed it in 1890. (See plate 10, National Geographic Magazine, vol. 3, 1891.)

The appearance of Atrevida glacier was that of a rapidly wasting ice-

tongue, almost if not entirely stagnant in its bulb-shaped terminus. In but one section was pronounced crevassing seen, and that extended over only a small area, in which the ice was bulged upward into a small dome. This was so exceptional a feature in the desert of morainic waste that we took a photograph of it (plate 15, figure 1), interpreting it then as the result of some obstacle over which the glacier was flowing. Unfortunately this was the only photograph taken of Atrevida glacier—a fact which, however, indicates how little of exceptional interest this particular glacier presented in 1905.

Swinging past Terrace point, which bounds the outer end of the valley portion of the glacier on its western side, the Atrevida coalesces with the stagnant terminus of Lucia glacier, which had in 1905, and retained in 1906 (plate 17, figure 2), the same characteristics as those described above for the Atrevida.

Condition in 1906.—It was our intention in 1906 to cross the Atrevida on our way westward across Malaspina glacier, and until we had reached its very edge, late in June, 1906, we had no intimation of the striking change which had occurred in ten months (compare figures 1 and 2, plate 15). The alder-covered margin, which we ascended with such ease in 1905, was now transformed to a steep, jagged ice-cliff from which the vegetation had been stripped, down which moraine and boulders were steadily sliding, and from which huge fragments of ice were tumbling (plate 17, figure 1). The margin of the glacier had advanced somewhat and now rested in the fringing forest, which was being destroyed by the falling of ice-blocks and boulders into it (plate 16, figure 1). By this advance spruce trees over a half century old were overturned, uprooted, and battered by the forward thrust and the falling blocks of rock and ice (plate 17, figure 1). So frequent were these falls of ice and rock that traveling along the margin was distinctly hazardous, and so steep and jagged was the margin of the glacier that it could be ascended only by the use of ice-axes and the hewing of steps in the ice.

The sliding down of the moraine along the marginal ice-cliff was forming a talus which was rapidly advancing into the forest and including battered tree fragments—veritable tree trunk boulders. Where small streams descended, new alluvial fans were spreading out over the moss-covered floor of the spruce forest. The ice-margin was indeed the scene of rapid changes.

The advancing glacier had destroyed the ice-cave from which the stream issued in the previous summer, and the stream now issued from the very base of the ice, beneath a broken and faulted ice-cliff in which

FIGURE 1.—EASTERN MARGIN OF ATREVIDA GLACIER

It is destroying alder thicket, June 29, 1906. In 1905 this was a moderately sloping moraine-covered ice slope

FIGURE 2.—BROKEN MARGIN OF ATREVIDA GLACIER, JUNE 29, 1906, WHERE GLACIAL STREAM ISSUES

See Russell's photograph (Nat. Geog. Mag., volume 3, 1891, plate 10). This stream emerged from a large ice cave in August, 1905

ADVANCING EASTERN MARGIN OF ATREVIDA GLACIER, 1906

FIGURE 1.—BROKEN EASTERN MARGIN OF ATREVIDA GLACIER ADVANCING INTO FOREST

In 1905 this was an alder-covered moraine slope. Photograph by O. Von Engeln, July 10, 1906

FIGURE 2.—STAGNANT ALDER-COVERED OUTER LUCIA GLACIER FROM FLORAL HILLS, JULY 16, 1906

Atrevida glacier was in same condition in 1905

ADVANCING ATREVIDA AND STAGNANT LUCIA GLACIER, 1906

OUTER MARGIN OF ATREVIDA GLACIER

Showing the crevassing extended into the alder-covered (black) stagnant ice. Note concentric rings of breaking. Stagnant Lucia glacier on right in background. Photograph by O. Von Engeln, June 29, 1906, from crest of mountain shown in plate 15, figure 2, and in plate 19

there was distinct evidence of thrust faulting (plate 16, figure 2). At this point the forward movement of the glacier is estimated to have pushed the terminus ahead not less than 100 yards.

It was evident not only that the ice had advanced and become broken during the period of ten months since we last saw it, but that it was even then moving forward. By this movement great crevasses had been opened and the ice, hitherto blanketed by a thick cover of moraine, with forest superimposed on it in places, was now exposed to rapid ablation. As a result of this marked increase in exposure of ice to melting, great streams of turbid water were running away from the margin and down through the forest, where during the previous summer there had been only trickling brooks of clear water which seeped through the morainic soil as the underlying ice slowly melted. Some of these streams flowed where there had previously been no channel, and these were destroying the forest by the deposit of sediment. Others, occupying former brook beds, had cut them deeply, especially where flowing through loose moraine. Altogether it was a wonderful transformation for so short a period, and its effect was shown in Dalton creek, the main glacial stream from the Atrevida, which was greatly swollen as compared to its condition in the previous summer.

The next day, on ascending the low mountain which borders the eastern margin of the Atrevida, we had a bird's-eye view of the glacier from the same point where we had looked down on it the previous summer (plate 18). The change observed from this point of view was even more remarkable than that witnessed at the margin. The easily traversed, undulating surface of the moraine-covered outer portion beyond the mountain, and that part farther up the valley which in 1905 was clear ice and snow, were now transformed to a labyrinth of crevasses extending from one side of the glacier to the other. Melting had in places transformed the crevassed surface to pinnacled ice resembling that of a typical valley glacier ice-fall. It had also allowed so much of the moraine veneer to slide into the crevasses that the surface was no longer an undulating waste of moraine, but a broken mass, fully half of whose area consisted of clear glacier ice.

The zone of crevassing extended from near the head of the valley far out beyond the mountain base into the alder-covered terminal portion. It gradually died out in a series of great concentric gashes, bringing to view clear ice in the alder thicket (plate 18). The crevasses were crescentic and roughly parallel to the bulb-like expansion of the glacier beyond the mountain front. By the breaking of the ice, and by its melting,

the alder growth on the glacier was being destroyed, the soil being removed from around the roots, and the bushes themselves lowered into the crevasses.

Later in the summer we approached Atrevida glacier again, this time from the western side, where we looked down on it from Terrace point (plates 19 and 15, figure 2). From here it was evident that the ice was pushing up against the margin of Terrace point, and it was found that it had moved forward far enough to cover the camp site which Messrs Martin and Butler had occupied in the previous summer. We have no means of telling exactly how far the ice-margin had pushed forward here, but it had evidently advanced several hundred yards. Farther southward the Atrevida had pushed out into the morainic waste of the stagnant Lucia glacier, and its crevassed margin was distinctly higher than in the previous summer, when the unbroken, undulating surface was not noticeably different either in character or in level from that of the Lucia (plate 17, figure 2).

Contrast with Lucia glacier.—According to Mr Butler, who was on both expeditions, the lower stagnant portion of Lucia glacier shows no change in the ten months between the two visits to it (plate 17, figure 2). He believes, however, that above Floral pass there is far more crevassed ice than there was in 1905. It is therefore possible that a wave of advance is in progress in the Lucia, but that it has not yet affected the expanded lower portion. Being a much longer glacier than the Atrevida, the Lucia might well be expected to respond more slowly to the impulse which caused the 1906 forward movement of the Atrevida and the still earlier advance of the Galiano.

Past and future.—In the case of Atrevida glacier, a long period of repose and wasting has terminated in a sudden forward rush of such force as to break the ice into an impassable sea of crevasses. We do not know how long this period of repose had lasted. It certainly dates back before Russell's crossing in 1890, and judging from the maturity of the fringing forest and of the alder growth on its outer portion, it seems probable that this part of the glacier has been essentially stagnant and slowly wasting for not less than half a century. At the time of our visit, the forward thrust had not yet reached its maximum, and therefore we cannot tell how much farther it will extend; nor can we predict whether its effects in breaking the ice will outlast the first rapid forward rush. If the Galiano glacier may be taken as a guide, however, it may be expected that the forward movement will be short-lived and quickly followed by a period

CREVASSED OUTER PORTION OF ATREVIDA GLACIER

View was taken looking south from Terrace point. Site of photograph, plate 18, mountain top on right. This glacier was so uncrevassed in 1905 that it could be crossed anywhere. Photograph by O. Von Engeln, August 2, 1906

FIGURE 1.—SEA OF CREVASSES IN MARVINE GLACIER

At this point the glacier emerges from mountain valley. Here Russell easily crossed in 1890. Long-focus photograph by O. Von Engeln, July 30, 1906

FIGURE 2.—DETAIL IN CREVASSED EASTERN MARGIN OF MARVINE GLACIER AT BLOSSOM ISLAND

Photograph by O. Von Engeln, July 29, 1906

CREVASSED MARVINE GLACIER

of repose, accompanied by a return of the moraine-covered condition and growth of an alder thicket on the outer margin.

MARVINE GLACIER

Previous condition.—We did not visit this glacier (plates 20–23) in 1905, but had clear views of it, through field glasses, from several points, the nearest being that obtained by Messrs Martin and Butler on the western side of Floral pass, where only the Hayden glacier intervened. Russell crossed it near Blossom island in 1890, and on his retreat in 1891 he traveled over its seaward margin from point Manby to Kwik river, where it forms the eastern part of Malaspina glacier. Abruzzi and Bryant, in 1897, starting at Osar river, near point Manby, on the shores of Yakutat bay, entered on their explorations by first crossing the seaward end of that part of Malaspina glacier which is dominated by the Marvine. From the description of these explorers, it is evident that both Marvine glacier and the eastern part of the Malaspina, which the Marvine supplies, were then smooth and easily traversed. Our distant views in 1905 led us to believe that it was not then altered from this condition. Had the glacier then been crevassed even approximately as much as in 1906, when the broken surface was readily visible from a distance, even to the naked eye, we surely could not have overlooked it.

Condition in 1906.—In July, 1906, we traveled along the eastern margin of the Malaspina and Marvine glaciers to a point 3 or 4 miles beyond Blossom island, returning in August along the same route, in each journey crossing Hayden glacier with ease. Later we skirted the seaward face of the Malaspina as far as point Manby. We also looked down on it from several high points, so that in the course of the season we saw the entire Marvine glacier from the sea well back into its mountain valley.

The entire glacier margin, from point Manby well into the mountain valley to the north of Blossom island, is impassably crevassed. Where Marvine glacier emerges from the mountains it is a sea of crevasses from side to side and as far up the valley as we could look (plate 20, figure 1).* It is therefore now utterly impossible to cross this glacier where Russell traveled over it so easily in 1890. From this point to the sea, a distance of not less than 15 miles, the piedmont ice plateau is broken by a maze of crevasses, rendering the entire eastern portion of Malaspina glacier now impassable (plate 20, figure 2). This crevassed

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* Owing to an accident, by which I was upset in the Kwik river, the photographic plates which were in my pack were in the water about five minutes, which accounts for the bad condition of this and some of the other pictures.

area broadens seaward, starting with a width of 3 or 4 miles at the mouth of the mountain valley and expanding to a width of over 10 miles near the sea.

In the mountain valley the crevassing has produced a jagged, pinnacled ice surface (plate 20, figure 1), but out in the expanded portion of the Malaspina piedmont area the crevasses form great rents, with many table-top areas between—remnants of the former level-topped ice-plateau Owing to the elevation, the snow had not completely disappeared from this section in July; so that, excepting along the glacier margin, melting had not yet greatly modified the area between the crevasses. This fact clearly points to the conclusion that the crevassing is a result of movement in the season of 1906; for if the broken surface had been exposed longer to the air, melting would necessarily have produced much greater effect in rounding off the table-topped areas between the crevasses.

That the advance of Marvine glacier was in progress during the summer of 1906 was abundantly proved. The margin of the glacier was being pushed forward into the form of a jagged ice-cliff resembling that of Atrevida glacier (plate 21). During this forward push the ice had been broken into great blocks, and the morainic soil, which varied in depth from 2 to 15 feet, had been greatly disturbed. The broken ice-blocks, stained by a veneer of debris washed down over them, reminded one of some of the frost-riven granite cliffs of New England, and at a distance looked far more like rock than ice. Ice-blocks were seen to tumble from the glacier margin as we passed along it, and the morainic soil was constantly falling from the cliff and being incorporated in the new talus slopes and alluvial fans.

By exposing to the air so much ice that had previously been deeply blanketed beneath moraine and forest, melting was greatly increased, innumerable new streams were developed (plate 23), and the volume of Kwik river greatly augmented. That this process was then actually in progress was clearly proved by the changes which occurred during the month that elapsed between our journey to Blossom island and our return. In this interval some of the streams had grown noticeably in volume and headed farther back in the crevassed ice, in some cases having developed ice-tunnels; the talus slopes and alluvial fans had grown in area, and in places the ice-margin had become distinctly altered in form.

By the forward thrust and breaking of the ice, the forest growth on it was being destroyed (plate 22). Many of the trees were inclined at various angles; others had fallen down the ice-front or into the crevasses; and large numbers were seen or heard to fall during our passage along

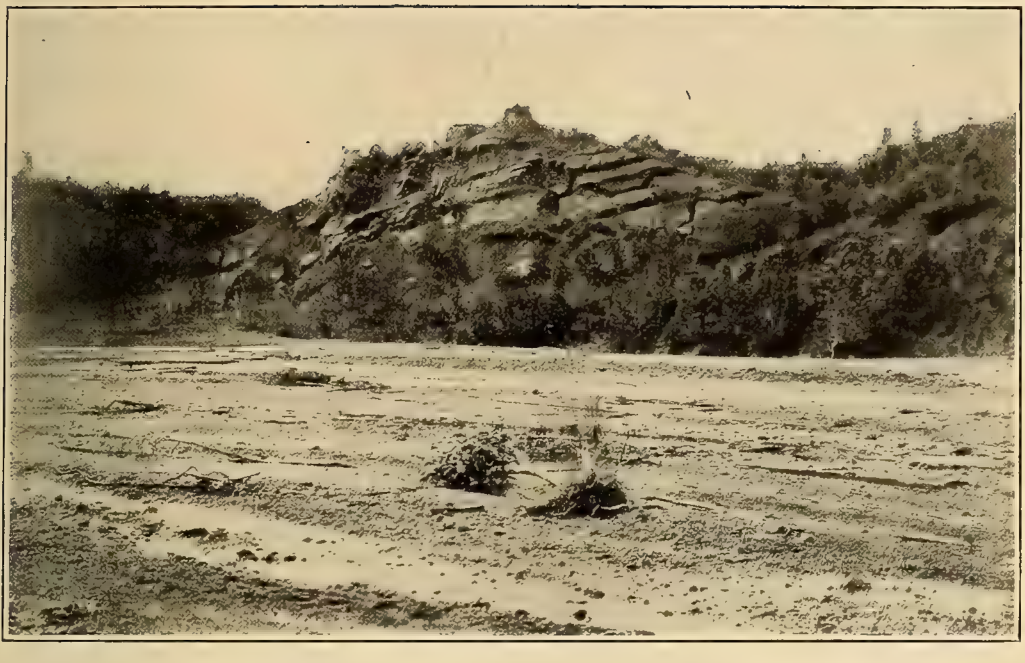


Figure 1.—Broken Ice Cliff of Malaspina Margin from Kwik River

Photograph by O. Von Engeln, August 11, 1906

Figure 2.—Ice of eastern Margin protruding through Forest Cover

Note broken ice blocks and overturned trees. Photograph from Kwik river, July 14, 1906

CREVASSED EASTERN MARGIN OF MALASPINA GLACIER

NEAR VIEW OF BROKEN ICE CLIFF OF EASTERN MARGIN OF ADVANCING MALASPINA GLACIER IN KWIK RIVER VALLEY

View is from near site of plate 21. Note ice blocks and overturned trees. Photograph by O. Von Engeln, August 11, 1906.

STREAM EMERGING FROM BROKEN EASTERN MARGIN OF ADVANCING MALASPINA GLACIER IN KWIK RIVER VALLEY

Forested, moraine-covered ice in background. Newly formed alluvial fan in foreground. Note destruction of vegetation. Photographed by O. Von Engeln, August 9, 1906

the ice-front. In many cases the soil had been removed from around the roots, and in consequence the vitality of the plants had been so sapped that their leaves had assumed the colors of autumn. Of these trees, fallen or otherwise, none were seen which had not completely developed their leaves, which proves conclusively that the forward thrust, along this margin at least, had its beginning after the spring season. Many of the cottonwood trees growing on the margin of the glacier were at least fifty years old, so that the essentially stagnant condition of the glacier, now abruptly interrupted, must have had a duration of at least half a century.

Rapid geologic changes.—The sudden transformation to liquid water of this latent supply, locked up in ice and blanketed beneath debris, has opened possibilities for rapid geologic changes succeeding a long period of stagnation and inactivity. This was well illustrated by the changes that occurred in the glacier margin immediately back of a camp site which we occupied on the west side of the Kwik. Early in July a small stream emerged from the broken ice and flowed past our camp, passing through a small lake in which it was building an alluvial fan (plate 23). During our stay at this camp we were every few minutes disturbed by the sound of falling ice-blocks, the crashing of falling trees, and the sliding down of large quantities of morainic soil. The melting ice supplied so much water that streams of liquid mud were constantly descending the ice-face, building up mud-flow fans along the base of the ice into which one dared not step. These deposits advancing into the fringing forest are rapidly destroying it (plate 23).

On our return a month later this small stream was greatly swollen, the fan was much larger, and the lake was nearly destroyed. In the meantime the detailed form of the glacier was totally altered. Leaving some supplies cached here for three days, on our return we found them almost undermined by the stream, which in the meantime had more than doubled its volume.

Since the entire eastern margin of the Malaspina, not only along Kwik valley, but also along the Yakutat Bay front, is in a similar condition, this sudden supply of water, acting on the morainic debris residually accumulated through years of slow ablation, is producing important changes over a wide area. It is a marvelous change, and in a single season more work of transportation and deposit has been accomplished than for scores of years immediately preceding. Another season of exposure to sun and rain will have removed most of the accumulated debris and forest from the margin of this advancing and broken glacier.

Change in subglacial stream course.—One rather peculiar effect of the advancing Marvine glacier was illustrated at Blossom island, situated in the bay where the western margin of the Hayden and eastern margin of Marvine glaciers unite. Streams supplied from the Marvine, and from several small valley glaciers, unite here to form a fairly good-sized river, which, after expanding in a small lake at the ice-margin, emerges to pass into a subglacial tunnel, from which it escapes as the Kwik river after a journey of 5 miles under the ice.

Just before our visit the Blossom Island lake had been greatly enlarged, covering an area several times its present size and rising 25 or 30 feet above its present level. The proof of this rise was the presence of a recently deposited layer of fine glacial mud, the occurrence of stranded icebergs above the lake level, and the retarded development of vegetation. In the areas that had been submerged the annual plants had only just begun to sprout, although it was the middle of July, and the alders and willows had only begun to put out their leaves, while some of the bushes nearer the lake had not begun to sprout.

In seeking a cause for this expansion of the Blossom Island lake, we found that the course of the outflowing stream had been entirely changed. Formerly it had flowed out through a small bay in the ice at the junction of Hayden and Marvine glaciers, doubtless disappearing in an ice-tunnel. The forward push of Marvine glacier had evidently destroyed this tunnel, but it had not completely destroyed the bay in the ice through which the water flowed on its way to the tunnel. About a mile to the north a new outlet had been developed under Hayden glacier, which is not subjected to the forward thrust. The newness of this outlet was proved by the fact that the great torrent of water was rushing under the glacier without the development of an arch. The current licked the ice-foot at the base of a cliff fully 200 feet high, from which large masses of ice were falling every few minutes. Occasionally great slices, thousands of tons in weight, slumped into the torrent to be swept in pieces under the glacier. By this action a bay over a hundred yards long had already been eaten into the glacier; and beyond this, for a distance of several hundred yards, the ice under which the stream flows is broken by slumping.

The shifting of a subglacial stream course by the advance of Marvine glacier, evidently the work of the season of 1906, is therefore another of the peculiar effects accompanying the remarkable advance of the glaciers of this region. When the new outlet was opened it must have caused a sudden increase in the volume of the Kwik. In fact, it is probable that our packers witnessed it; for a cache containing most of our provisions,

placed one evening in what seemed a safe position, was swept away early the next morning by a sudden rise in the river.

OTHER TRIBUTARIES TO MALASPINA GLACIER

Between the advancing Atrevida and Marvine glaciers lie Lucia and Hayden glaciers. It has been stated that the former may possibly be advancing in its upper portion; but there is no sign of any advance in the Hayden. It pushes down to and coalesces with the Marvine, slightly deflecting it, but not contributing greatly to the ice-supply of Malaspina glacier. For a short distance near the head of the Kwik, ice supplied by Hayden glacier forms the eastern margin of the Malaspina, and in this section there is little crevassing; but, with the exception of this small area, there is no place between point Manby and Blossom island where one can ascend to the surface of Malaspina glacier without encountering almost impassable crevasses.

West of Marvine glacier the Seward emerges from its mountain valley, spreading out to form a portion of the Malaspina ice-plateau. From a distant view that part of the Malaspina which Seward glacier supplies does not appear to be greatly crevassed, the broken area dominated by the Marvine ending quite distinctly where it comes in contact with the ice supplied by Seward glacier; but where the Seward emerges from its mountain valley, there is a great deal of crevassing. Benno Alexander, a member of my party, accompanied the Duke of Abruzzi on his ascent of mount Saint Elias, in the course of which he frequently traversed Seward glacier. On viewing this glacier from the crest of Blossom island in 1906, Alexander was convinced that it was far more crevassed than in 1896. He states that in 1896 it was easy sledging across that part of Seward glacier where now, from a distant view, it seems that sledding would not be possible. This suggests that possibly Seward glacier is also advancing, but that the wave has not yet affected the more stagnant piedmont terminus in the Malaspina ice-plateau.

SUMMARY OF OBSERVATIONS

The facts above stated for individual glaciers show that there is a remarkable change in progress in at least several of the many valley glaciers of the Yakutat Bay region. This change is in the nature of a paroxysmal thrust, as a result of which the ice is badly broken, as if a push from behind had been applied with such vigor as to break the rigid, resisting ice-mass in front. The effect of this thrust is in each case felt from far

up the mountain valley well down toward the terminus of the glacier, and, in the case of Marvine glacier, to the very end.

In both Variegated and Atrevida glaciers the ice has been broken for a distance of from 5 to 7 miles; in Marvine glacier the breaking extends fully 15 or 20 miles. The crevassing in all cases extends completely across the valley portion of the glacier and down into the stagnant or nearly stagnant moraine-covered margin. In all cases the thrust is accompanied by a distinct forward movement at the terminus, and in at least three cases—the Variegated, Haenke, and Atrevida glaciers—there has been a distinct thickening of the ice as a result of the forward thrust. It is probable that there has also been a thickening in Marvine glacier, but since we did not visit it in 1905, we have no comparative observations on which to base a definite statement.

The remarkable advance of these glaciers is recent, and, in the case of four of them, has mainly, if not entirely, occurred in the ten months preceding June, 1906. Not only is the movement recent, but it was actively in progress at the time of our visit in the summer of 1906. In at least one case, that of Galiano glacier, a forward movement has occurred and died out during the interval between 1890 and 1905. There are indications that an advance is beginning in some of the glaciers, notably the Lucia and the Seward, but there are others which show neither signs of the coming of such an advance nor of its having already come and gone.

From these facts it appears that, for some reason, there is a striking and rapid change in progress in the glaciers of the Yakutat Bay region, interrupting a period of long quiet and affecting different glaciers at different times. One glacier has passed through the cycle of change; others entered on it in 1906; still others show signs of the beginning of such a cycle; but in other cases there are no indications of its approach.

Consideration of Hypotheses

THE PROBLEM TO BE SOLVED

Such a remarkable change in the condition of glaciers as to transform an unbroken, moraine-covered valley glacier to a sea of crevasses in the short interval of ten months—a phenomenon, so far as I know, not hitherto recorded—calls for a special explanation. The phenomena in the field clearly prove that there has been a wave of advance passing through the glaciers with such rapidity as to break the ice, instead of causing a slow forward movement, such as commonly results from normal climatic

changes. This fact demands for its explanation a cause sufficiently powerful to start such a rapid wave.

HYPOTHESIS OF CLIMATIC CAUSES

In seeking an explanation for the advance of a glacier, one naturally, first of all, considers climatic causes. In the attempt to apply this explanation to the case in hand, two serious difficulties have arisen. In the first place, no such profound result from climatic variation has ever been noticed before. In the second place, it seems impossible that the amount of additional snowfall required to start such a tremendous wave of advance could be supplied by seasonal variations, for it would mean a sudden and great increase in the snowfall, interrupting a half century of fairly uniform conditions. There is no direct evidence against this hypothesis, for we have no rainfall records in this region; but nevertheless we seem warranted in dismissing it merely on the basis of improbability, for such a profound, sudden change in climate would of itself be more remarkable than the phenomenon which we are called on to explain.

HYPOTHESIS OF POSSIBLE UPLIFT

A second hypothesis that has been considered is that of uplift. Concerning this, also, we have no definite facts to advance; but against it may be argued the improbability of so decided a change in so short a time as to profoundly disturb the glaciers radiating from a mountain center. To produce such an effect, an uplift would need to amount to at least hundreds of feet and to take place in a brief interval of time. In fact, since the glaciers all head in lofty, snow-covered mountains, up whose slopes damp ocean winds rise and on which the snow-cover descends to within two or three thousand feet of sealevel, it is very doubtful if the amount of snowfall on the mountains would be greatly increased, even if there had been a sudden uplift of hundreds of feet. This hypothesis is so utterly improbable that it also may be dismissed without further consideration.

HYPOTHESIS OF CHANGE OF GRADE

We gave consideration to the hypothesis of change of grade in the valley glaciers as a result of alterations of level accompanying the earthquake of 1899. This explanation also lacks probability, for a change in grade sufficient to transform a nearly stagnant valley glacier to one as badly crevassed as an ice-fall is wholly unlikely. Moreover, in the case of Atrevida and Variegated glaciers at least, the grade was essentially the

same in 1906 as in 1905, and in both cases it was far too low to account for movement rapid enough to so break the ice (plates 8 and 19). It is evident that the cause of the crevassing must be sought not in the influence of grade, but in an acceleration of motion due to a push from upstream, acting on low grade glaciers whose forward motion up to 1905 was so slight as to admit of the concentration of surface morainic debris.

HYPOTHESIS OF BREAKING BY EARTHQUAKE SHOCKS

Two hypotheses involving earthquake effect were considered and quickly dismissed. One of these was that some recent earthquake had so shaken the region as to break the ice into the condition observed in 1906. This hypothesis was readily disproved on inquiry, when it was found that there has been no notable earthquake in the Yakutat Bay region since 1899.

The second earthquake hypothesis was that the shock of 1899 was responsible for the conditions of 1906 by actually breaking the ice, though the effects are only just now appearing at the surface. Numerous facts disprove this improbable hypothesis, the most fatal being the convincing evidence of forward movement actually in progress in the summer of 1906. As has been shown above, the charge is associated with and apparently the result of a forward push, so that any hypothesis which does not include this is necessarily eliminated.

HYPOTHESIS OF SNOW SUPPLY RESULTING FROM EARTHQUAKE SHAKING

This hypothesis is, in a word, that during the earthquakes of 1899 the mountains from which the snow supply of these glaciers is derived were so vigorously shaken that great avalanches of snow and rock were thrown down to the névé, starting a vigorous wave of advance whose effects have now reached the glaciers described above. Of all the hypotheses which have suggested themselves, this alone seems capable of explaining the phenomena. Opposing it no facts have been discovered, while there is much in its favor.

The earthquake of 1899 was of unusual vigor.* Throughout a period of seventeen days the region was subjected to earthquake shocks, some of which were of exceptional strength, notably those on September 10 and September 15. The most violent shocks were so strong that they were plainly recorded on the seismographs in Europe, Japan, and at cape of Good Hope. During these earthquakes the coastline of Yakutat bay was greatly deformed—in one place, on the west side of Disenchantment bay, the beach being hoisted forty-seven feet above sealevel. The people living

* Tarr and Martin: Bull. Geol. Soc. Am., vol. 17, 1906, pp. 29-64.

at Yakutat, the nearest inhabited point, report long-continued, terrifying shaking of the ground. Some prospectors who were in camp near Variegated glacier made a similar report, adding to it the statement that during the most violent shaking the air was filled with noises like thunder, as huge avalanches of snow and rock descended the neighboring mountain slopes.

There can be little, if any, question that during these shocks immense quantities of snow and rock were thrown down from the steep mountain slopes. The snowline descends to within two or three thousand feet of sealevel, and the mountains rise to elevations of from ten to fifteen thousand feet, so that the snow-covered slopes occupy a great area (plate 11). By glacial erosion and other forms of denudation the valley slopes have been greatly steepened, and therefore over large areas the snow lies in very unstable positions. Even under ordinary conditions snow avalanches may be seen at almost any time among these lofty mountains. This is especially true during and after snowstorms, which are frequent in September, the month during which the earthquake of 1899 occurred. When to this heavy snow blanket, which mantles the steep mountain slopes, is added a repeated shaking of the mountains, it follows that a great and sudden addition to the névé must in all probability have taken place.

A comparison of the present conditions with photographs taken by Professor Russell clearly shows that in some cases, at least, there was a downshaking of materials from the steep valley slopes. In two cases where these comparisons were possible—the valleys of Black and Galiano glaciers—there have been notable changes. In Black Glacier valley extensive areas, which in 1890 were covered with vegetation, are now bare rock. In Galiano valley large patches of snow and ice which clung to the steep slopes in 1890 have now disappeared (compare figures 1 and 2, plate 13). In this valley also the effects of recent great avalanches are still plainly visible, and on Hayden glacier there is an enormous mass of debris which evidently has fallen recently.

That there was abundant cause for an unusual down-sliding of snow, ice, and rock in 1899, and that this downfalling actually did occur, I believe the above facts amply prove. A notable accession of supply in the névé region, such as these facts indicate, must of necessity start a wave of advance in the glacier, and this wave would naturally be a great one—far more powerful and sudden in its effects than is liable to be produced by normal climatic variations. One possible difficulty in the way of acceptance of the explanation here proposed is the briefness of time for the

transmission of this great wave; in fact, this difficulty has led me to question whether it may not be necessary to seek an explanation in an earthquake of more remote date. Facts bearing on this question are not at hand.

So far as I know, no similar phenomenon is reported from other regions for comparison. It is well known that normal climatic variations cause a slow wave of advance, but exactly what would follow upon a sudden and abnormal accession of snow supply is not clear. So far as I am able to consider the question, however, I am led to believe that it would not be proper to make use of the results of normal climatic variations as an exact parallel in a consideration of the effects which would follow upon a sudden accession of enormous quantities of snow and ice. It seems probable that so great an increase in supply would start a wave of such power as to crowd upon the rigid and nearly stagnant ice of a wasting glacier. Such a crowding, by applying a rapid thrust against the ice, might well push it so hard and fast as to cause it to slide forward, and cause it to move by massive breaking instead of by interstitial movement. It is conceivable even that the effects of such a wave might advance faster than the wave itself.

To state the latter point more fully, when a great wave of advance, starting in the névé region, reaches the glacier proper, it might exert sufficient pressure to push forward the ice in front of it, and thus cause it to break, pile up, and advance even down to the very margin. In this way the effects of a great wave of advance might well extend clear to the end of the glacier long before it would be possible for a normal wave to reach the terminus. Some such process as this seems demanded by the fact that miles of ice are suddenly, in a period of not over ten months, changed absolutely from a surface easily traversed to a labyrinth of crevasses.

If ice near the bottom of the glacier is moving by viscous flow, the sudden application of pressure, due to great accession of supply, may cause a more rapid flow of the bottom layers, and thus greatly rupture the rigid upper layers.

Glaciers that are not advancing

That some glaciers are advancing and others not, suggests the possibility that there is some selective action, as a result of which certain glaciers are immune from the effects which have caused such a remarkable advance in others; but this may be only apparent. If the cause for the advance is earthquake shaking, it ought in time to affect most, if not all,

the glaciers of the region; but there is no reason to expect that the effect would occur at the same time, or to the same degree, in the different glaciers. There are at least three reasons why the effect may vary in time, or in intensity, or in both. Of these, doubtless the most important is the length of the glacier, and in this connection it is notable that one of the smallest glaciers, the Galiano, has already passed completely through a period of advance; and that Atrevida glacier now shows the full effects of the advance, while its longer neighbor, the Lucia, has not been affected, excepting possibly in its upper valley portion. On the other hand, the long Marvine glacier, a far greater ice-stream than the Lucia, has entered on the maximum development of the effects, while some very short glaciers, like the Black, just south of the Haenke, show neither signs of having passed through the period nor of its approach.

These contrasts, however, may be due to one or both of the other two possible causes for variation in the effects of the earthquake shaking. One of these is the steepness of the valley walls, especially in the snow-field section; the second is the amount of snow available. Obviously there must be great differences in the steepness of the mountain slopes and in the amount of snow available in unstable position; and, according as these conditions favor or oppose a sudden increase in the névé supply, there will be marked variations in the rate and amount of consequent advance. A possible fourth cause for variation in the effects of the earthquake shaking is difference in intensity of shocks from place to place. While undoubtedly the entire region was severely shaken, it is probable that some portions of the area escaped with far less disturbance than others, and consequently with a much smaller addition to the névé.

There are therefore adequate explanations for the differences observed in the condition of the various glaciers. Some, quite certainly, will never show the effects of the earthquake shaking; others, which have not yet advanced, may be expected to push forward at a later time. It cannot be definitely predicted when this will occur in any individual case, but from the rapidity with which the advance has swept throughout the entire length of some of the glaciers, it seems probable that the effect of the wave will become manifest within a very short period of time in all cases where the cause for the advance has operated. Therefore it may be predicted that, in all probability, this region will be one of great interest to glacial geologists in the next few years. It is highly probable that Malaspina glacier, for so long a period a nearly stagnant ice-plateau, will become crevassed throughout its entire length, and, advancing along its margin, possibly enter the sea, discharging icebergs both into Yakutat bay and the

open Pacific along a coast where at present the glacier front is faced by strips of alluvial fan and beach.

Consideration of the future Condition

In addition to the possible future advance of other glaciers, it is interesting to consider what may be expected to follow on the advance of those glaciers which have already been affected. On this point Galiano glacier throws much light. If we are warranted in basing our conclusions on this glacier, we may infer that in each case the wave of advance will soon die out, that stagnation will follow, and that ablation will proceed to again mantle the margins with a cloak of morainic debris.

Much of the moraine formerly available for this mantle will have been lost as a result of the breaking caused by the recent advance. Some of it will have tumbled down into the crevasses, and much of it will have been carried away by the newly born streams. The removal of this material will leave less to blanket the ice and to prevent it from wasting away. For this reason a more decided recession of the margin of the glaciers would be expected in the immediate future. This more rapid recession may be expected to be increased by a diminished supply of ice; for, since the shaking down of quantities of snow in the supply ground has in places removed the accumulation of many years, until such time as its place is taken by additional snow accumulation, there should be a decided deficiency in supply. One may therefore fairly predict a distinct recession following the notable present advance.

Geologic Effects

The sudden breaking of extensive areas of glacier ice and the advance of the broken glacier margins give rise to some very notable geologic changes. By the advance in at least two instances, the course of good-sized glacial streams has been completely altered. The cracking of the glaciers opens to ablation an enormous area of ice hitherto protected by debris or buried beneath the surface of the previously smooth glacier. Our observations on Hayden glacier prove that in the last of July and early August the level ice-surface is lowered 4 inches a day by ablation. By the great increase of exposed ice the volume of water emerging from the glaciers is quickly and enormously increased. The accumulated moraine on the surface, and particularly along the glacier margins, furnishes an immense quantity of debris; so that not only is the volume of the glacial streams greatly augmented, but their activity in transporting and depositing sediment is increased many fold (plate 23).

The advancing ice pushes against and overrides deposits previously made. It also buries and mixes with the deposits of debris the battered fragments of both bushes and trees which grew in front and on the surface of the glaciers (plates 21–23). Under the variable and ever-changing conditions accompanying this deposit and overriding, there is being accumulated a remarkable deposit of stratified and unstratified material mixed with plant fragments.

Possible economic Effects

In this unsettled region the economic effects of the sudden advance of the glaciers have not been of marked importance; but if the advance extends to the entire Malaspina and to the Hubbard and Turner glaciers, there may result some effects of distinct importance to man. Already the ice-cliff of Turner glacier has been extended fully a mile (plates 11 and 12) and the area of iceberg discharge thereby greatly increased. If Turner and Hubbard glaciers also push forward, the amount of ice discharged into Yakutat bay may far exceed that of the present. If Malaspina glacier advances far enough to enter Yakutat bay and the Pacific ocean, as it may possibly do, the discharge of icebergs will constitute a menace to navigation along this coast.

Farther to the northwest the town of Valdez is situated on an alluvial fan directly in front of Valdez glacier. If earthquake effects should start a wave of glacier advance there similar to that witnessed in the Yakutat Bay region, that city would be in danger both from the advancing ice and from the increased volume of water discharged from it.

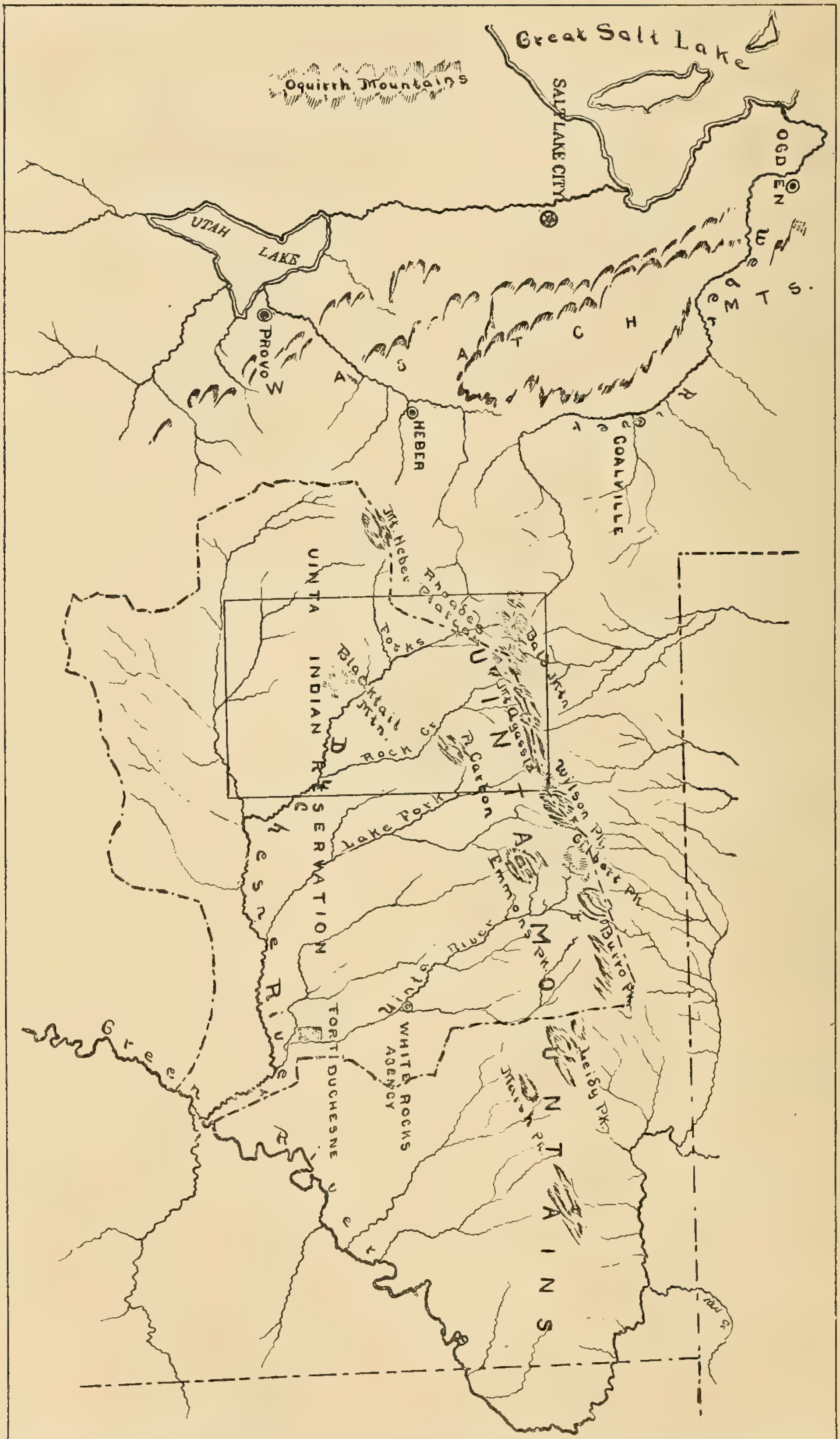
In several places in Alaska trails extend over glaciers, and such an advance as that in the Yakutat Bay region would of course destroy these. In the consideration of routes for railroads, it is proposed, in some instances, to lay the tracks over or near the terminus of stagnant glaciers. Such a sudden advance of glaciers as is described above would of course completely interrupt travel along such routes. In this region of frequent earthquakes it is not at all unlikely that glaciers of other sections may during the present century receive an impulse of advance similar to that which has visited the Yakutat Bay region. It is certainly a possibility which ought to be taken into consideration in building towns, roads, and railways.

Conclusion

In a region where the recent history of the glaciers has been almost uniformly one of recession, such a sudden advance as has been described in this paper is of interest and importance. So far as is known to the

writer, the phenomenon is unique; and yet, if the cause assigned is the correct one, it is one which may well be expected in those mountain glacier regions that are subject to violent earthquakes. In fact, if a great shaking will cause a profound forward movement, it is probable that a lesser shaking will cause a smaller advance. It is possible that some of the observed changes in the fronts of glaciers are attributable to former earthquakes instead of climatic changes.

The beginning of the advance in this case has been witnessed, and there is every reason for believing that it will be continued, and that in the next few years other glaciers will be affected. The uniqueness and importance of the phenomenon makes it highly important that its progress and effects should be carefully studied. It will be a great pity if some means is not found by which the glaciers of this region can be carefully watched for the next few years.



GENERAL MAP OF NORTHEASTERN UTAH FROM WASATCH MOUNTAINS TO GREEN RIVER

Showing location of areas discussed

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UINTA MOUNTAINS*

BY SAMUEL FRANKLIN EMMONS

(*Read before the Society December 29, 1906*)

CONTENTS

INTRODUCTION

The Uinta mountains form one of the most interesting and unique ranges in the Cordilleran system, in that they have a typical anticlinal structure with east-west axis and show no evidence of igneous action connected with their uplift.

In them are exposed, moreover, the only Paleozoic outcrops arising above the covering of Tertiary sediments in the upper part of the Colorado Plateau region, which thus furnish the sole connecting link between the Wasatch uplift on the west and that of the Rocky mountains on the east.

TOPOGRAPHY OF THE REGION

Topographically, they form a rather flat elliptical dome about 150 miles in length along their main axis and 20 to 25 miles in average

* For the general location map (plate 24), showing the geographical position of the area discussed, I am indebted to Professor C. P. Berkey, who used it in his paper, "The Stratigraphy of the Uinta Mountains." Bull. Geol. Soc. Am., vol. 16, 1904, plate 89.

Manuscript received by the Secretary of the Society May 20, 1907.

width. The interior of the ellipse has a general level of about 10,000 feet, out of which rise sharp, narrow ridges and peaks of horizontally bedded quartzites to elevations of 12,000 and 13,000 feet. The plateau-like surface between the peaks consists of a series of shallow, glacial basins, well clothed with pine forest and studded with innumerable glacial tarns. The streams that drain these basins run in a series of rapidly deepening canyons with nearly vertical walls that reach depths of 3,000 to 4,000 feet before they emerge into the open plain country on either flank. On the broad, flat spurs between these canyons gently sloping Tertiary beds lap over the upturned Mesozoic and Paleozoic to elevations attaining in some places 10,000 feet, which, together with the abundant accumulations of moraine material, effectually mask much of the under geology, especially on the northern flank. This general description applies more particularly to the western two-thirds of the range. Toward the eastern end the general elevation of the interior decreases, the higher peaks reaching elevations of only 8,000 to 9,000 feet, while the mountain mass widens very considerably and the structure becomes correspondingly complicated. The single anticlinal fold becomes double, while at the eastern extremity, before the older rocks disappear entirely under the Tertiary beds, the axes of folding take a more north and south direction and the uplift ends in two isolated anticlinal billows that raise their crest a little above the sea of horizontal Tertiary beds that now surrounds, but once covered, a great part of the present mountain mass.

The central core of this mountain mass consists of a series of quartzite beds, over 12,000 feet in thickness, whose age has long been in doubt. On three published geological maps they have been assigned successively to as many different periods—on the Fortieth Parallel maps to the Carboniferous, on the Powell map to the Devonian, and on the Hayden maps to the Silurian—whereas in point of fact they do not belong to any one of the three.

Purpose of the Paper

A generation has passed away since these maps were made, during which time the advance in geological knowledge of the West has been so great and the change in methods of work so radical that it is difficult for the younger generation of geologists to appreciate the conditions under which geological work was then done. It is my purpose in this article to explain first how it came about that such conflicting statements were made, incidentally pointing out the difference in conditions and methods of work between that time and the present day, and finally, as a result of a reconnaissance during the past summer, to give my conclusions as to

the age of the quartzite series and of the Paleozoic beds which overlie them.

State of geological Knowledge

The only systematic exploration of the entire range was made by the Fortieth Parallel party under my charge, in the summers of 1869 and 1871. In the same years Powell made his famous explorations of the canyons of the Colorado, and in so doing traversed the eastern end of the range in his boat journeys down the meandering canyons of the Green river.

In the summer of 1871 Hayden made a hasty reconnaissance along the northern slopes of the range, penetrating the central core at a single point near the head of Blacks fork, where he found Carboniferous fossils in the flanking limestones and "suspected" that the underlying quartzites might be Silurian from their resemblance to the Potsdam sandstones. During the seasons of 1874 and 1875 Powell headed parties that studied the geology of the eastern part of the range and the surrounding Cretaceous and Tertiary regions. From that time until 1903 there is no record of any geological study of the range.

At the time when the Fortieth Parallel field work was being carried on, what was known of the geology of the Cordilleran region was mainly derived from observations of geologists accompanying military expeditions, generally as surgeons. It may be summed up as follows:

On the Great plains, especially about the upper Missouri river, Meek and Hayden had established the Cretaceous section and named its five divisions, but were uncertain whether the upper coal-bearing member might not more properly be classed as Tertiary. The beds beneath them were recognized as Jurassic from their fossils, while the red sandstones under these were judged from their position and lithological characteristics to be probably Triassic. Unconformably over the whole lapped various series of fresh-water Tertiary beds, whose age was not yet determined, though in the very summer in which the Uinta work was being carried on the first vertebrate remains were being collected from the Eocene beds of the adjoining Green River basin.

In California the auriferous slates had recently been determined to be of Jurassic age, which was specially interesting as affording a decided negative to Murchison's hitherto generally received dictum, that gold only occurs in rocks as old as the Silurian.

From the wide mountain region between the Sierra Nevada and the Rocky mountains, popularly known as the Great American desert, Carboniferous fossils had been brought back by the various government

expeditions that had penetrated it; but beyond this nothing was known of its geological column.

Methods of Work

The work of the Fortieth Parallel geologists, it must first be noted, did not claim to be a survey, but was explicitly called an exploration. It was carried on in regions that not only had never been mapped, but of which the topography, except in its very broadest features, was entirely unknown.

Each working party consisted of a geologist, a topographer, and a barometer-carrier, with the necessary camp men and military escort. The necessities of topographic work required the occupation of every peak in a mountain range; hence the location of the successive camps was made rather with reference to the possibility of reaching such peaks than because they were the best points from which to study the geology of the surrounding country. In regions like the Uinta mountains, difficult of access and remote from any lines of communication, any revisiting after the completion of field work was quite impracticable.

So large were the areas laid out for the field work of each season that the utmost speed was necessary in order to go over the whole ground before snow rendered geological work impracticable. Thus the Green River sheet, which covers an area of over 15,000 square miles, including the greater part of the Uinta mountains, was completed during the single field season of 1871, and for the study of the Uinta mountains during the two seasons of 1869 and 1871 less than three months could be given to actual field work, no small part of which the geologist in charge of the party had to devote to tasks not strictly geological.

The general system of work was to construct in our minds, from field observations, a tentative set of geological divisions, based primarily on lithologic distinctions, and, from each successive peak visited, to work out the structure of the surrounding country as indicated by the lines of outcrop exposed. As we had no maps, we used only breast-pocket notebooks in which to record our observations; hence the ideas we formed as to the geological structure of the country visited could not be fully put on paper until the topographer's notes for the whole area surveyed had been platted and engraved, and our tentative geological columns modified or confirmed by the determination of our fossil collections by specialists. Owing to a peculiar combination of circumstances, over two years had elapsed after the final completion of our seven years of field work before all this was accomplished.

In the case of the Uintas, lithologic distinctions in the Mesozoic and more recent beds were sufficiently persistent to permit a ready tracing of the structure, especially in the eastern part of the range, where the anticlinal arch is lower and has been more completely denuded of its Tertiary covering. This is not the case, however, with the Paleozoic beds; for, although the west end of the range, which we first visited, is separated from the Wasatch by a covered gap only 10 or 15 miles in width, it is practically impossible to trace there the lithologic succession of beds below the Weber quartzite observed in our key-section in the latter range.

Our first visit to the Uintas, at the close of the field season of 1869, was curtailed by shortness of provisions, due to the forced abandonment of our wagon soon after leaving Provo valley, and when we finally reached the valley of the Duchesne, which was the eastern limit of that season's work, it was found impossible to ascend the canyon above the forks because of beaver ponds, which were impassable to our animals. We were therefore obliged to abandon its exploration and climbed Rhodes spur, on its western side, in order to reach the summit of the range at Bald mountain, from which we shaped our course westward again.

The field work of 1871 was carried on from Fort Bridger, on the Tertiary plains to the north of the Uintas, as a supply camp, from which two trips were made across the range to its southern flanks; but the necessities of the work did not justify going so far west again as the main Duchesne river, and thus a considerable gap was left between the two seasons' field work at the very point where the best and most continuous Paleozoic exposures are to be found.

When, in the winter of 1874–1875, the working up of our material was so far advanced that we could draw in the geological outlines on the Green River sheet, there was a question as to what color should be given to the great quartzite core of the Uintas. Its estimated thickness amounts to about 12,000 feet. Above it is an uncertain thickness of beds, largely limestones, with some siliceous members, the fossils collected from which were determined by the paleontologists to be decidedly Upper Carboniferous, and for the most part rather high in that formation. In his one trip into the interior of the range, when he had climbed mount Agassiz at the head of Bear river, Mr King had collected from the talus slopes of that peak a well preserved Upper Carboniferous *Productus* in Uinta quartzite.

In the typical Wasatch section, as shown in Weber canyon, there are 5,000 feet of Carboniferous quartzites, with 2,000 to 2,500 feet of calcareous and argillaceous Carboniferous beds above them, and about 9,000 feet, mostly limestones of Carboniferous, Devonian, and Silurian age,

between them and the Cambrian. Below the latter, in other parts of the range, a still larger body of quartzite is found, having a thickness of at least 12,000 feet. To one or the other of these quartzites it was evident the Uinta quartzite must correspond. Its lithological constitution resembled the latter more than the former, though the resemblance was not very close and as a factor of correlation it was not considered of prime importance. To correlate it with this formation involved the assumption of an unconformity as the only way of accounting for the disappearance of the Devonian and Silurian formations of the Wasatch section, which were evidently unrepresented. No such unconformity had been observed, however, and one of the rules laid down by Mr King for geological mapping was not to represent any such features as faults or unconformities which were not proved by actual evidence in the field. Hence, with some misgivings, but as the only alternative, the doubtful quartzite was correlated with the Weber, and so mapped. That such an unconformity had actually been observed by Major Powell in the deep canyons of Green river, which we had been unable to explore through want of boats, was only known to us some years later, for the following reason:

Major Powell's Investigations

At the close of the field season of 1871 Major Powell paid me the compliment of asking me to explain to him my ideas of the Uinta structure, saying that his observations in his boat journeys down the Colorado, being necessarily confined to the immediate vicinity of the river, were difficult to coordinate, and he felt it would be of great help to him in working them out to thoroughly understand the Uinta uplift, which was evidently the key to the whole section. At that time he did not mention the unconformity by erosion, nor was the question of the origin of Green river discussed; but in other respects we compared notes freely and agreed in all essential points.

When, a few years later, after he had borrowed a proof-sheet of our topography of that region, it was learned that he proposed to publish a volume on the Uinta mountains in the near future, it was realized that he would probably secure a priority of publication over us, since, though the part of my manuscript relating to the Uintas was already written, it must necessarily wait until the report of the entire Fortieth Parallel region was completed before it could be published.

In a vain attempt to obviate this, Mr King, on November 15, 1875, caused 12 printed copies of the geologically colored Green River basin

map, signed and dated in his own handwriting, to be distributed to as many of the leading geologists of the country.

When the Powell report appeared (without any reference to our previous studies) the most important difference between his determinations and mine was as to the age of the Uinta quartzites, which he tentatively assigned to the Devonian, having found an unconformity by erosion between them and the overlying Carboniferous. As Whirlpool canyon, in which the unconformity was seen, was in a region of very complicated faulting and folding, Mr King thought it possible he might have been misled in his observations by the effect of perspective in observing faulted outcrops. It was, however, impossible at that late date to verify this fact, but we were certain that a quartzite series of that thickness could not be Devonian. A foot-note was therefore inserted in our report,* stating that if such unconformity exists, the quartzite series, which we had called "Weber," must represent rather the great quartzite formation underlying the Cambrian of the Wasatch. My later geological work in the West has confirmed this conclusion, as I stated in my article "Orographic movements in the Rocky mountains."†

Recent Investigations

It still remained, however, to determine what part of the Wasatch section is represented in the western Uintas, whether the unconformity can be detected there, and what is the true correlation between the formations there represented and the Grand Canyon section, on which Powell had based his divisions. I had hoped that long ere this these questions would have been finally settled by an areal survey of the region, made by geologists of the U. S. Geological Survey, and have hence deferred any further reference to them. In the summer of 1903, at my suggestion, Mr J. M. Boutwell made a reconnaissance examination of the iron ore deposits on Rhodes spur, in the course of which he obtained an undoubted Mississippian fauna from the limestones‡ overlying the great quartzite series, thus definitely proving that the latter could not be Weber.

During the same summer Mr Charles P. Berkey had an opportunity of studying in considerable detail the geology of the region around the Duchesne river, and discovered a considerable thickness of shaly beds beneath the limestones and separated by a fault from the Uinta quartzites, neither of which had been noted by me. He also claimed to have found two unconformities by erosion in the Paleozoic series, and on the

* Descriptive Geology, vol. ii, p. 199.
† This Bulletin, vol. 1, 1879, p. 256.
‡ U. S. Geological Survey Bulletin no. 225, p. 225.

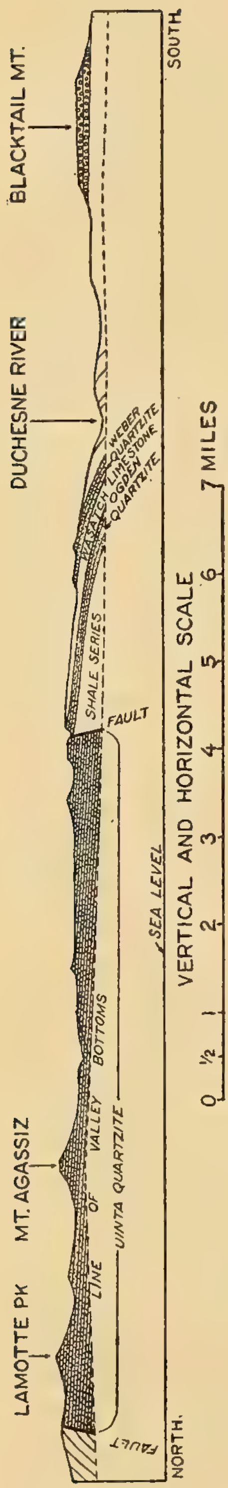

FIGURE 1.—*Cross-section of the Uinta Mountains along east Wall of Duchesne Canyon.*

basis of these new facts constructed a geological column which should reconcile the discrepancies between the relative views assumed by him to have been maintained by Powell and myself respectively.*

During the past summer, through the courtesy of Mr F. B. Weeks, who was making the entire circuit of the range in a study of its Paleozoic exposures, I was enabled to examine the Duchesne valley and the region to the east of it, not visited in my original work, which, as it happens, contains the most continuous section in the entire range, outside the Green River canyons. The information thus obtained, supplemented by general data kindly furnished by Mr Weeks, has enabled me to determine the general features of Uinta structure with sufficient accuracy for immediate presentation, though there are many questions whose final solution must still await a detailed areal survey that may not be undertaken for many years.

My observations bear testimony to the intelligence and acumen of Mr Berkey's work, though I am forced to differ with him on some important points, and hence my conclusions are somewhat at variance with his.

The Bear, Weber, and Duchesne rivers all have their source on the same bit of plateau at the west base of mount Agassiz, near the northern crest of the range, the first two flowing northward, then westward, to empty into Salt lake, while the latter courses south for 25 to 30 miles, and then bends eastward to join the Green or Colorado river. The first 12 miles of the Duchesne's course are in the even and almost horizontally bedded Uinta quartzites, through which it flows in a narrow, practically impassable canyon, bounded by nearly vertical cliffs. The canyon widens out quite suddenly in the shales beyond the Iron Creek fault, but still continues to form an imposing gorge 2,500 to 4,000

* This Bulletin, vol. 16, p. 517.

feet below the flat-topped spurs on either side. About 8 miles below the Iron fault, near the site of the proposed town of Stockmore, the so-called West fork comes in from the west after running for 25 miles along the strike in the red beds of the Permian or Trias. Below the forks, in the softer Mesozoic rocks, the valley becomes still wider and contains considerable bottom land, while the bounding ridges have worn down into low hogbacks, except where protected by a covering of Tertiary beds, lapping up on the spurs or occasionally standing out as residual mesas, like Blacktail mountain in the section (figure 1).

The magnificent section of Paleozoic beds exposed along the walls of the gorge is rendered rather difficult to read, through the abundant slips or faults parallel to the stream, by which narrow slices of the walls are let down a few hundred feet here and there, probably by sapping, so that portions of the cliff sections are duplicated. This may account for Mr Berkey's tendency to overestimate the thickness of his various divisions of the Paleozoic rocks.

Another peculiarity of topographic structure is observable at the head of the side ravines tributary to the main valley when they occur in limestone formations. In the midst of a remarkably well watered region, these ravines have no running water, and in their basin-like heads are many minor depressions without outlet, such as are characteristic of moraine ridges, but in shape rather longitudinal than round. On either side of the main valley, near the mouth of the ravine where these were first observed, there are large springs issuing from the base of the cliffs, in streams 15 to 20 feet wide, with sufficient volume of water to supply irrigation ditches which extend to the arable lands many miles down the valley. Hence the explanation that suggested itself was that, in the easily soluble limestones, surface waters had eaten their way along cracks and small faults, finding their run-off in such springs, and had thus eroded increasingly large caves that had finally collapsed, producing something analogous to the sink-holes of the western Appalachian region. This hypothesis was later confirmed by the finding of a typical Kentucky sink-hole with circular limestone walls and a funnel-shaped bottom. The structure is developed on so large a scale in this region that it deserves a special name, for which sink-hole or karst topography is suggested.

Geology of the Region

The geology of the region is not so easy to read as at first glance would appear, because the cliff sections along the valley are complicated by the slips or faults mentioned above, and on the flat-topped spurs, owing to

the generally low angle at which the beds stand and the peculiar topographic forms, the true succession of the respective exposures is often

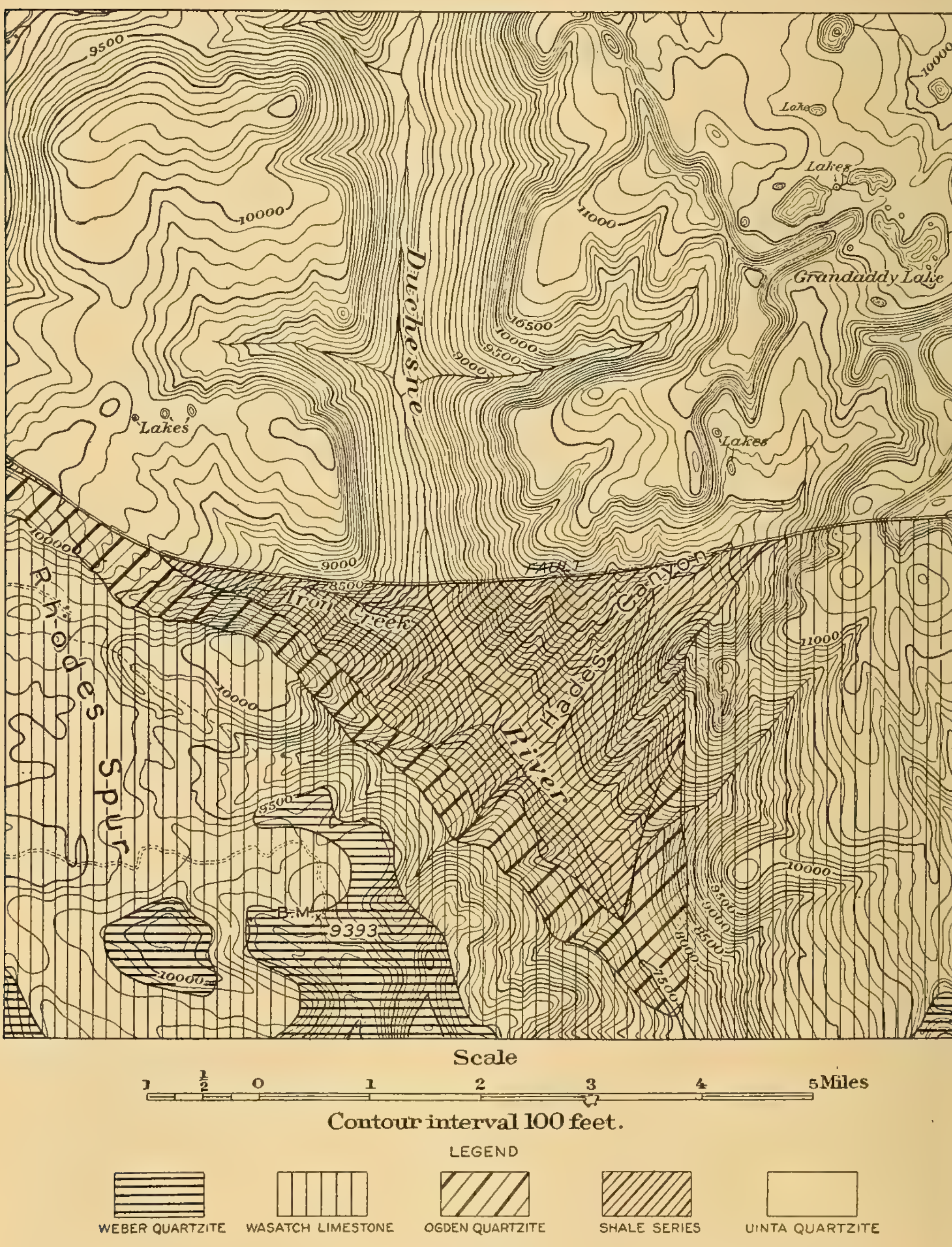

FIGURE 2.—*Geological Sketch Map of Duchesne Canyon Region, Western Uinta Mountains.*

difficult to determine. The lithologic constitution of the beds has suffered a remarkable change from the Wasatch section, considering the short distance that separates them.

The Wasatch limestone has shrunk to about 1,000 feet of buff, cherty, calcareous beds, alternating in the upper part with white sandstones. Although the limestones are always light colored, they often present a red or striped appearance in cliff exposures, and thus resemble rocks of the same horizon in the Grand canyon of the Colorado, where they are stained by waters seeping down over their face from red shales above, and were hence called by Powell the Red Wall limestones. They carry Pennsylvanian fossils in the upper part, and Mississippian in the lower.

Beneath these are quartzites with interbedded conglomerates and sandy shales, generally white or greenish, often red by oxidation, which are in extremely variable thickness, reaching a maximum in the Duchesne valley of 1,100 feet. Mr Berkey's surmise that these correspond to the Ogden quartzite (now considered Ordovician), though as yet unsupported by paleontologic evidence, is considered a probable assumption, and the name has been provisorily retained. If there be an unconformity by erosion, it would be most naturally placed between this and the Shale series below, because of the variation in thickness of this siliceous member, it being entirely wanting on the northern flanks of the range; but no direct evidence of erosion could be detected and the conglomerate has not the characteristics of a true basal conglomerate.

In the Duchesne valley the Shale series consists of about 1,200 feet of thin-bedded, dark, argillaceous shales, in which we were unable to detect the pyrites to which Mr Berkey refers. Their best exposures are in Hades Creek and Iron Creek ravines, adjoining the fault. They have no relation, as the latter name might suggest, to the deposits of iron ore which occur, as Mr Boutwell has noted, in the Wasatch limestones much higher in the geological column.

The thickness of the Shale series is also variable, being nowhere so great as in the Duchesne valley; but it is never entirely wanting, as is at times the Ogden quartzite. In my original field notes I find mention of a few hundred feet of greenish shales observed at various points, supposed to be part of the upper members of the Uinta quartzite.

The Iron Creek fault has not the structural significance that Mr Berkey would assign to it. It can only be traced 7 or 8 miles on either side of the Duchesne valley, though similar strike faults occur at various points along the southern flanks of the range, more frequently where the strata have taken a sudden downward bend, so that the existence of the fault is less evident than on the Duchesne. In spite of its striking prominence in the valley bottom, the Iron Creek fault could not be detected on the plateau-like summit of the spurs on either side of the Duchesne, unless one knew of its existence and made a special search for it; for on the

east, as Mr Berkey himself remarks, the Ogden quartzite is in juxtaposition to the Uinta quartzite and perfectly conformable in angle, and on Rhodes spur, where the former caps a bold escarpment facing north, overlooking the interior plateau, the shales are effectually concealed by a talus of huge blocks of greenish white Ogden quartzite, likewise conformable.

Above the Wasatch series is a great siliceous member consisting largely of white calcareous sandstones and gray quartzites, which I correlate with the Weber quartzite,* and for which Mr Weeks estimates an aggregate thickness of 2,200 to 2,700 feet.

This is presumably the series of beds at the base of which Mr Berkey placed his main unconformity; but in spite of a most careful search, continued by Mr Weeks throughout his circuit of the range, we were unable to find the basal conglomerate on which Berkey's scheme of correlation is mainly based. Negative evidence is confessedly somewhat dangerous ground upon which to deny the existence of an unconformity by erosion, since such unconformity involves no discrepancy of angle, and the positive evidence of overlap is not necessarily present, while it is rare, even in long and well exposed canyon sections, to get unmistakable evidence of the unevenness of an old eroded surface in the hollows of which the later beds were deposited. In the present case their superior resistance to erosion and the slowly steepening angle of dip have combined to leave patches of the Weber beds in abnormally high positions on the spurs (see map, figure 2), which probably led Mr Berkey to suppose they came there by overlap. Even did such an unconformity exist, however, his scheme of correlation based on it would fail, since it assumes that it is the same unconformity that Powell observed in the canyon of Green river; but there the Red Wall limestone, which corresponds to the Wasatch of the Duchesne, lies above this unconformity. Even Mr Berkey's hypothesis of a sea that was slowly retreating westward and then rapidly readvancing could hardly account for the same beds being deposited above the erosion interval in one place and below it in another.

Above the Weber quartzites are cherty limestones, followed by calcareous sandstones and argillaceous shales, in which the calcareous element decreases upward until they end in a series of deep red shaly beds which, owing to their easy erosion, are apt to form hogback valleys.

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* It has been considered advisable to use the old Fortieth Parallel names of formations and not attempt to make subdivisions characterized by local names until the region is areally surveyed. For the great central quartzite series Powell's name, Uinta, has been retained, because it is not only the most appropriate, but also possesses priority in published description. As used on the Fortieth Parallel maps, this name indicated simply an area of Tertiary beds of probable different ages, but not yet differentiated.

This series has a thickness of about 2,500 feet and carries an Upper Carboniferous and Permian fauna. It is in this series that the unconformity by erosion, if it exists, is likely to occur. It is suggested by the apparent overlap of the beds; moreover, a widespread unconformity is known to exist at this horizon in Colorado and elsewhere.

Above these in typical development are the light red, thin-bedded sandstones, generally classed as Triassic, which in turn are succeeded by shales and limestones carrying characteristic Jurassic fossils.

The accompanying map (figure 2), of which the topographic base is a copy of a portion of the Hayden Peak quadrangle of the Forest Reserve Survey by the U. S. Geological Survey, shows the distribution of the above described beds as far as they occur on the area mapped. Unfortunately the map extends only a few miles south of the Iron Creek fault, so that a large part of the Paleozoic exposures do not appear on it.

Structure

In the area represented the beds do not strike due east and west, but to the north of east on the east side of the valley and to the north of west on the west side, which means that the valley runs approximately in the axis of a secondary anticlinal fold, with axis at right angle to that of the main anticline. In dip the beds steepen to the southward from the average angle of 5 degrees in the Uinta quartzite to 10–17 degrees in the area mapped; then to 25 degrees just south of it, and finally to 45 or even 60 degrees along a varying line that follows the southern flanks of the ranges. A typical cross-section of the range is given in figure 2, which is reduced and somewhat generalized from an actual section drawn to natural scale on a line following the top of the spur east of the Duchesne. Just north of the main crest of the range there is generally found to be a sharp break line in the Uinta quartzites, on the south of which they incline from 2 to 5 degrees southward, and on the north dip steeply northward up to angles of 45 degrees or more. There has evidently been faulting in the region where this remarkable change of dip takes place, but, owing to the similarity in lithological constitution of the rocks on either side, neither the throw nor even the location of the fault can be determined. It is not, however, continuous along a given east and west line, as seems to have been assumed by Powell, who probably reasoned from the most strongly marked of these faults, which runs along the northern edge of the Red Creek Archean body, in the Browns Park region; this fault, however, has a strike of from 16 to 20 degrees to the north of east and crosses Green river to the south of Horseshoe canyon; hence

could not coincide with the faults north of the crest, which probably are arranged en echelon. Along the southern flanks the faulting is apt to take place near the sudden steepening of the dip, which is observable in most every cross-section, and beyond which the beds resume their former low angle and extend southward under the Tertiaries in a broad, shallow syncline. Thus the uppermost of the Mesozoic beds involved in the original Uinta arch, the Laramie formation, first reaches the surface again 100 miles to the south in the Book cliffs, just north of the Rio Grande Western railway. The sudden steepening of the dip on a given line along the flanks of a mountain uplift is a common phenomenon, and notably well developed along the east face of the Front range of Colorado, and can best be explained as the result of a tangential shove, as illustrated by some of Bailey Willis's experiments in mountain building. On this hypothesis the faulting would be an expression of the relief of strain along lines of extreme folding tension.

Correlation

Having had an opportunity in recent years of personally examining the Grand Canyon section, on which Powell based his Green River Paleozoic section in the Uintas, I am better able to correlate the latter with that exposed in the Duchesne region as shown above. My interpretation would be as follows: The remnants of red beds on the Coconino plateau correspond to the Permo-Carboniferous beds on the Duchesne; the Upper Aubrey limestone to the cherty limestone immediately above the Weber quartzite; the Lower Aubrey to the Weber quartzite itself, and the Red Wall to the Wasatch limestone. In either region there is uncertainty, through want of fossil evidence, as to the Devonian and Silurian. In the Grand Canyon region a Devonian fauna has been discovered in a thin series of rocks separated from the Red Wall limestone by a slight unconformity, but the Silurian is apparently wanting. In the Uintas no fossils have yet been found below the Wasatch limestone. The Ogden quartzite, whose name has been temporarily retained for the Duchesne section, has in the Wasatch recently been determined to lie below beds of Ordovician age. It is probable, therefore, that both Devonian and Silurian are wanting in the Uintas, and that the Tonto of the Grand canyon is represented by the Ogden quartzite or the Shale series, or by both together.

Powell's Lodore series is supposed to represent the Tonto series of the Grand canyon, though in his Uinta report he said Carboniferous fossils had been found in it, which was evidently an error, probably caused by a displacement of labels during transportation.

The Uinta quartzites occupy a position corresponding to the Pre-Cambrian series in the Grand canyon which Powell included under the general name of Grand Canyon series. This has since been subdivided into the Chuar, Grand Canyon, and Vishnu series, each separated by an unconformity, only the lower member of which, the Vishnu, resembles lithologically the Uinta quartzite.

Powell failed to recognize the Permo-Carboniferous in the Uintas, as he did in the Grand canyon, but in other respects his geological column in the Uintas above the Carboniferous corresponds fairly well with that of the Fortieth Parallel, though the formations are given different names and their lines of diversion are placed at somewhat differing horizons.

The greatest uncertainty that still remains is in regard to the proper correlation of the Ogden quartzite and the Shale series. If we correlate with the Wasatch section, they correspond best with the Cambrian of the Big Cottonwood section; if with the Grand Canyon section, they fit best the Tonto, which consists of shales and sandstones.

There is still some uncertainty as to the location of Powell's unconformity in the western Uintas, if indeed it exists there. Owing to the want of precision in his published statements, it is difficult to verify his observations in the field. As already stated, I think its most probable place is between the Ogden quartzite and the Shale series.

The Uinta quartzites I regard as undoubtedly of Pre-Cambrian age, but, like most Pre-Cambrian formations in the West, which are widely separated and generally barren of fossils, its exact correlation will for a long time probably remain in doubt.

Origin of Green River

The statement of Powell, in his volume "Exploration of the Colorado River of the West," with regard to Green river, to which he assigns an antecedent origin, thereby furnishing a striking proof of the slowness of the movement of mountain uplift, picturesquely comparing the contemporaneous uplift of the Uinta mountains and the corrasion of the Green River canyons with movement of a saw-log relative to a buzz-saw, have been accepted and quoted by many writers of text-books on geology. My theory that it is a superposed river, based on the occurrence of remnants of Wyoming conglomerate (Bishop Mountain conglomerate of Powell) resting unconformably on all underlying formations, and so situated that when connected together they must have entirely covered that part of the range through which the Green River canyons are now cut, has received less notice; nevertheless it has been accepted by such authorities as

Professor Ed. Suess and Professor Wm. M. Davis. I have elsewhere* stated some of the physical impossibilities which Powell's hypothesis involves, and will therefore not enlarge upon them here. I have always been a firm believer in the theory that the uplift of a mountain chain is immensely slow, and, further, that it is continuing at the present day, as I have had occasions to demonstrate by facts disclosed in the underground workings of mines. In the Uinta mountains it is easy to find facts in support of this theory without resorting to the hypothesis of the antecedent origin of Green river. As is well known, the forming of the Uinta arch commenced at the close of the Cretaceous, as is evidenced by the fact that the flanking Tertiary beds lap unconformably over the upturned edges of the older strata, which when exposed are seen to stand at angles of 30 degrees and upward. There are three series of Tertiary beds filling wide basins both north and south of the Uintas—the Wasatch (or Vermillion Creek of the Fortieth Parallel), the Green River, and the Bridger formations, all of Eocene age and with an erosion interval between each. Now, while each of these series of beds occupy a practically horizontal position throughout their basins, at the very edge of the Uinta mountains they can be seen to be slightly upturned against their flanks, the lowest series at the greater angle, 15 degrees or even 20 degrees in places, and the more recent beds correspondingly less, which means that the continued rising of the mountain mass had dragged up the adjoining edges of the beds resting against their flanks—a movement which, being continuous, has necessarily been greater in the case of the older beds.

* Science (new series), vol. vi, July 2, 1897, no. 131.

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VOLCANIC NECKS OF THE MOUNT TAYLOR REGION, NEW MEXICO*

BY DOUGLAS WILSON JOHNSON

(Read before the Society December 29, 1906)

CONTENTS

INTRODUCTION

Several years ago, while studying the geology of the Albuquerque quadrangle, New Mexico, I had a distant view of that geological wonderland made classic by Major Dutton in his report on the Mount Taylor region. Since that time I have been anxious to visit the district, more especially to get a closer view of the remarkable volcanic buttes in the valley of the Rio Puerco, which Major Dutton interpreted as remnants of necks formerly connecting with overlying volcanoes which have long since been worn away.

The buttes are most abundant in an open valley excavated by the Puerco river through the eastern part of the great lava sheets surrounding the Mount Taylor volcanic mass, the valley being open to the north and south, inclosed on the west by the ragged escarpment of the larger Mount Taylor mesa and on the east by the smaller Prieta mesa. The mesa surface is from one to two thousand feet above the valley floor; the valley is from 8 to 12 miles wide east and west, and the area studied is about 18 miles north and south.

* Manuscript received by the Secretary of the Society April 24, 1907.

The desire to visit the district was strengthened by the tendency on the part of some observers to regard vertical columnar structure and undisturbed, surrounding sediments as features not to be expected in volcanic necks, but rather as indicative of some other origin for buttes which exhibit such features. Thus the Devils tower, in Wyoming, has been referred by Professor T. A. Jaggar, Junior, to a laccolithic origin partly because it rises above undisturbed sediments, and its beautiful columnar structure is more or less nearly vertical. In a recent textbook, "Elements of Geology," by Professor W. H. Norton, it is implied (page 276) that vertical columns would not be found in a volcanic neck. Dutton states that vertical columns are found in many of the Mount Taylor buttes, and rather implies that they are surrounded by undisturbed sediments. It was believed that a careful study of the buttes in the Rio Puerco valley, with possible alternative interpretations in mind, might serve to determine which features are characteristic of volcanic necks, which of remnants of laccoliths or columnar sheets of lava, and which are common to both topographic forms.

An opportunity to visit the region was offered in the spring of 1906, during a geological excursion through parts of New Mexico, Arizona, and Utah. The excursion, which included a wagon trip of over 1,500 miles during a vacation of four months, was made possible by appropriations from Harvard University and the Massachusetts Institute of Technology and private gifts from Mr George G. Crocker, Senior, and other friends of the Institute. Ten days were spent in a trip to the Mount Taylor region, where the principal buttes between Cabezon and a point a few miles north of Juan Tafoya were studied and the data presented below were collected. The district included between these two Mexican villages was selected because it contains, according to Dutton, the largest and best preserved buttes in the Mount Taylor region.

I was accompanied in the field by Dr H. W. Shimer, of the Massachusetts Institute of Technology, who made a study of the stratigraphy of the Puerco valley, the results of which will soon be published. The photographs reproduced on plates 27 and 29 were taken by Doctor Shimer. I am indebted to Professors W. M. Davis, J. B. Woodworth, and T. A. Jaggar, Junior, for reading the manuscript of this paper and offering criticisms and suggestions.

Purpose of the Investigation

Briefly stated, the objects of the trip were as follows:

(1) To ascertain further details regarding the structure of the supposed necks and their relation to the surrounding sediments.

(2) To see if it were possible to harmonize the facts observed in the field with some other theory of origin than that elaborated by Dutton.

(3) To determine as far as possible what features may be used as critical evidence in discriminating between volcanic necks and remnants of eroded laccoliths or columnar sheets of lava.

The Conclusions reached

The studies led to several conclusions which are stated more fully in subsequent pages, but which may here be summarized as follows:

(1) Those buttes of the Mount Taylor region observed by us are undoubted volcanic necks, as determined by Dutton, and do not admit of any other interpretation.

(2) Vertical columnar structure is apt to characterize the upper portions of volcanic necks, as should be expected from theoretical considerations and as is fully exemplified in many of the Mount Taylor necks. Such structure, therefore, can not be used as evidence in discriminating between necks, and remnants of laccoliths or columnar lava sheets.

(3) Frequent sections about many of the necks show them to be surrounded by horizontal sediments which have not been disturbed by the intrusion of the necks. Disturbed sediments, therefore, are not a necessary accompaniment of volcanic necks, and the absence of such disturbance can not be urged as an evidence of some other origin for any butte whose nature is in doubt.

(4) Vertical columns which curve outward at the base, as in the Devils tower and in some of the Mount Taylor necks, are more apt to occur in volcanic necks than in remnants of laccoliths or columnar sheets of lava.

(5) In general, it appears that the selection of any specific structural feature as a guide to the critical distinction between volcanic necks and remnants of laccoliths or columnar sheets of lava is unsafe. There are few, if any, features which might not occur, to some extent at least, in buttes having different origins. The concordant testimony of a variety of evidence from a large number of different buttes, however, can hardly leave any doubt as to their origin, especially when the general geological history of the region is taken into account.

Literature

The only detailed account of the buttes of the Mount Taylor region is that by Dutton in his paper, "Mount Taylor and the Zuñi plateau." The paper discusses several problems of wide scope, the volcanic buttes being but one of the interesting features considered. The fifteen pages

devoted to the lava-capped mesas and the buttes, however, give a good idea of the essential features with which we are concerned, and offer the best explanation yet available as to the manner in which the great cylindrical masses of lava came up through the surrounding sediments. A dozen illustrations show the typical appearance of the buttes.

As seen in the field, the nature of the buttes is so evident that no one who has seen them would doubt the manner of their origin. It is therefore not surprising that Dutton regards them as true volcanic necks and does not discuss alternative theories or interpretations. We read on page 167 that "the experienced geologist who has traveled much in these regions will recognize their significance at a glance," and on page 168, that "the interpretation here given is such as would be accepted at once by any geologist, but the general reader might like some further proof of it. He can have an abundance." Then follows a detailed description of many of the buttes, which will be referred to again in subsequent pages.

Dutton was unable to visit the two finest buttes in the region, Cabezon and Great neck, but saw them from a distance. My own observations included these two and a number of intervening ones; so that the data collected were not repetitions of those presented by Major Dutton, but rather supplementary to them.

Professor Newberry, in his report on the geology of the exploring expedition from Santa Fé to the junction of the Grand and Green rivers, figures the great Cabezon peak on plate XI of the report, but does not discuss its origin, except to say that it has a general resemblance to the Needles of the San Juan valley (page 117). Concerning the Needles he writes (page 107):

> "This is a mass of erupted rock, rising with perpendicular sides from the middle of the valley. . . . Its altitude is about 1,700 feet above its base; above the river, 2,262 feet. It is everywhere surrounded by stratified rocks, and its isolated position and peculiar form render its origin a matter of some little doubt. My conviction, however, is very decided that its remarkable relief is due to the washing away of the sediments which once surrounded it, and which formed the mold in which it was cast. In no other way can I imagine its vertical faces of 1,000 feet to have been formed."

The figure of Cabezon, while not very accurate, shows the vertical columnar structure, and the figure of the Needles (plate X) indicates that the same structure is found in that apparent neck.

Reference has been made to the Devils tower, or Mato Tepee, of Wyoming, and its interpretation as a remnant of a laccolith. Professor Jaggar, in his paper, "Laccoliths of the Black Hills," mentions the occurrence of

a somewhat annular type of drainage about the tower, the presence of agglomerate exposed at one place near its base, the compact character of the rock composing the tower, and its association with undoubted laccoliths in the same general region as some of the evidences in favor of a laccolithic origin for the tower, but says (page 266):

"The most conclusive evidences against a subjacent conduit to the Mato Tepee mass are the presence of black shale in the agglomerate, the undisturbed horizontal beds which the tower rests upon, and the vertical columns."

General Geology

The sedimentary rocks of the region consist of yellow and gray Cretaceous sandstones and shales, generally with a gentle dip to the northward in the Puerco Valley district. After the tilting of these beds the

Figure 1.—*Sketch Map of the Mount Taylor Region.*

Black dots show location of some of the necks.

region was reduced by erosion to a surface of rather faint relief. This peneplain neatly bevels across the inclined layers, as can be distinctly

seen in the walls of both the Mount Taylor and the Prieta mesas. The amount of dip is generally so small, however, that in a limited exposure the beds appear horizontal. In speaking of the exposures about the volcanic buttes, the imperceptible northward dip will be ignored and the beds regarded as horizontal, except in those cases where local tilting is evident.

On this surface of faint relief was built the massive cone of the Mount Taylor volcano and the surrounding lava flows. For detailed descriptions of the main volcano, the lava flows, and the minor cones rising above the flows, the reader is referred to Dutton's essay. According to Dutton, the lava flows are not derived from the main volcano, but from numerous vents scattered over the tableland. Repeated outflows from these vents interlaced to build up a lava cap several hundred feet in thickness and some hundreds of square miles in area. Cinder cones were built on the lava cap in places, indicating occasional explosive phases at some of the vents.

Thus closed the period of vulcanism, and there followed a long era of quiet, during which we have no evidence of any recurrence of lava outbreaks. With the exception of recent basalt fields farther south and west, wholly distinct from and not to be confused with the lavas of the Mount Taylor and Prieta mesas, there is no trace whatever, so far as the region has been studied, of any recurrence of volcanic activity since the period of eruption which formed the great lava cap of the region. Concerning the age of the flows which make up this cap, Major Dutton writes (page 177):

"They were Tertiary; probably Middle Tertiary. . . . None of them can be regarded as recent in any sense whatever. Nowhere on the surface of Mount Taylor or of its surrounding lava sheet has any fresh-looking rock been found. The traces of time are visible everywhere."

Since the close of the volcanic period, the history of the region has been one of erosion. The country of low relief and the lava cap which overspread part of it were subjected to renewed dissection. Deep valleys were cut through the lava cap into the underlying softer rock, and extensive sapping of these softer beds all around the edge of the lava cap caused continual decrease in the size of the mesa. The deepening and broadening of the Puerco valley has isolated the eastern end of the mesa forming the smaller remnant called Prieta mesa. Today we find that the lava cap and over 1,000 feet of the underlying sediments have been removed over extensive areas, so that we recognize in Mount Taylor mesa and its isolated remnants a tableland of sandstone capped by lava,

which represents only a portion of its former greater extent. The buttes occur in the eroded area.

The numerous vents from which the lava spread out to form the great surface cap must have connected with some kind of conduits extending downward through the sandstone to the depths from which the lava rose. As soon as the resistant cap was removed, the underlying sandstones would be quickly worn away; but here and there ought to be left standing some masses of resistant igneous rock representing the lava which hardened in the conduits. A view across the Puerco valley reveals many shafts or cylindrical masses of lava rising as buttes well above the valley lowland, produced by erosion of the softer beds. The conclusion is most natural that the buttes represent "necks" of lava which hardened in tube-like conduits leading from unknown depths up to vents on the former surface, the surface, together with the cones and flows which were built upon it, having been removed hereabout by erosion. Such a conclusion is strengthened if, like Dutton, one sees sections of such shafts of lava in the side of the mesa connecting above with cones and lava flows not yet wholly destroyed. He does not doubt that under the portion of the lava cap which still remains are many other such "necks" leading up to the cinder cones and other vents still seen on the surface of the cap, which will some day be revealed by the removal of the cap and the enclosing sediments.

It is essential to the better appreciation of what is to follow that the three main points in the history of the Mount Taylor region, as noted above, be kept in mind. These are, briefly, (1) the reduction of the region to a peneplain; (2) the occurrence of a period of volcanic activity during which the peneplain was covered with a lava cap derived from numerous vents; (3) the extensive erosion of the region, including the removal of the lava cap and underlying sediments from large areas, and the exposure of the shafts of lava which hardened in the conduits.

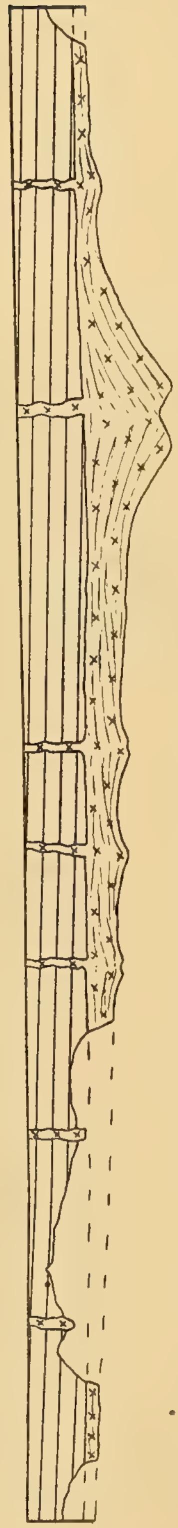

FIGURE 2.—*Ideal Cross-section, northeast-southwest, through Mount Taylor, Mount Taylor Mesa, Puerco Valley, and Prieta Mesa.*

Structural Details

We may now consider the structural details of some of the Mount Taylor buttes, after which it will be in order to examine critically the several theories which might be advanced in explanation of their origin. Doubtless most of the buttes have names by which they are known to the Mexicans, but as I was not able to learn these names in all cases, I designated the buttes by numbers in my notebook and will so refer to them now, adding the correct name when possible.

Number 1, Cabezon peak. This is probably the finest butte in the Mount Taylor region, although Great neck, described on a later page, is a close second. As stated in Major Dutton's report, the topographers who ascended Cabezon found its altitude to be 2,160 feet above the valley bottom. Its diameter is given as about 1,400 feet. A famous landmark

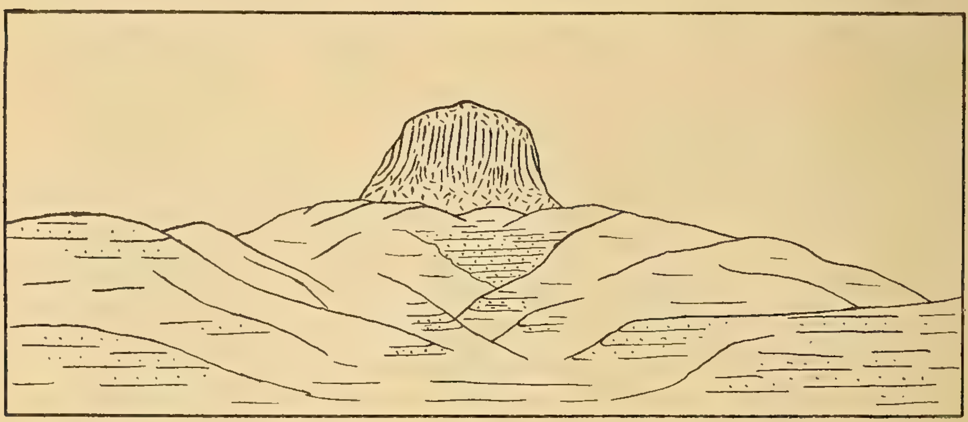

Figure 3.—*Cabezon, showing Exposure of surrounding horizontal Sediments.*

for many years, it has been figured in several of the early exploration reports. It is indeed a most striking feature in the landscape, with its dark shaft outlined against the sky or against the yellow sandstones of the surrounding country.

We approached Cabezon from the east, our first good view of the peak being that reproduced in plate 25, figure 1. From a point a few miles nearer we could see that the butte possessed fine vertical columnar structure, and that down toward its base the columns in places curved outward toward the periphery. The main tower rises above a circular terrace of Cretaceous sandstones which appear to be horizontal, but which are not well exposed on the east. The immediate base of the tower is more or less obscured by a talus of broken columns.

Continuing to the town of Cabezon, we obtained a fine view of the

FIGURE 1.—CABEZON PEAK FROM THE EAST
Showing relation of neck to surrounding country

FIGURE 2.—NEAR VIEW OF CABEZON PEAK FROM THE SOUTHWEST
Showing vertical columnar structure

CABEZON PEAK

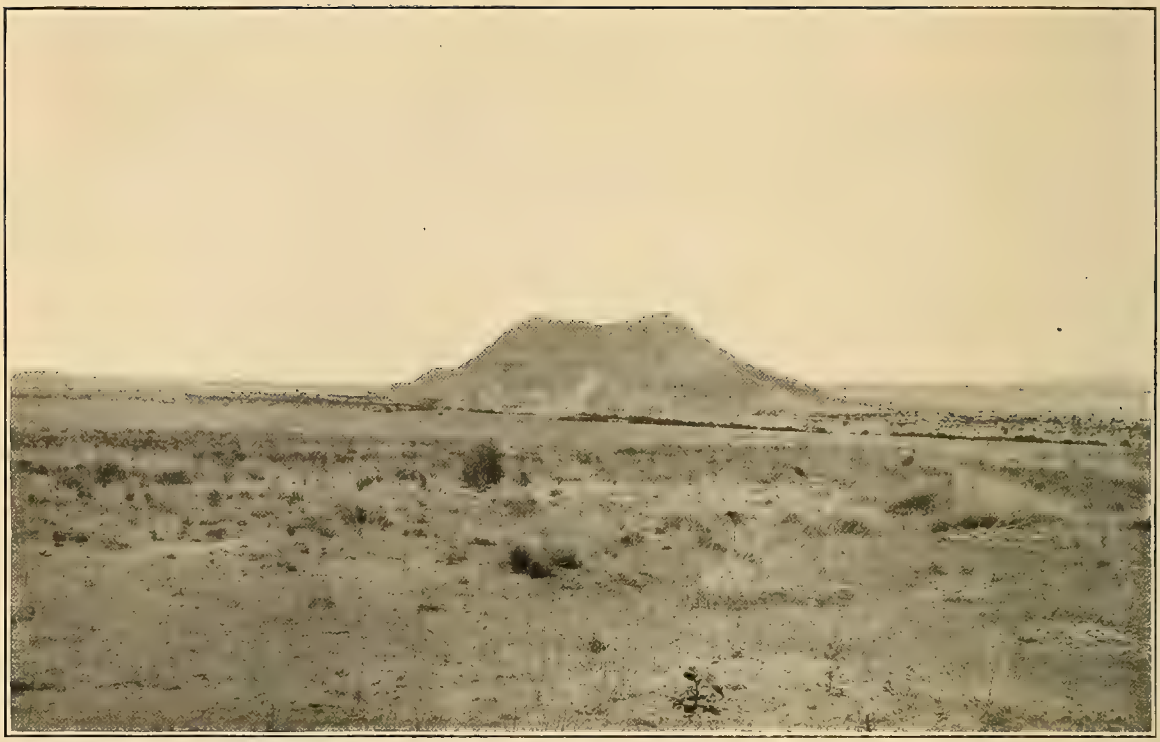

FIGURE 1.—TWIN PEAK (BUTTE NUMBER 12) FROM THE EAST

FIGURE 2.—CERRO COCHINO (BUTTE NUMBER 6) AND PRIETA MESA FROM THE NORTH

TWIN PEAK, CERRO COCHINO AND PRIETA MESA

butte, and observed that the horizontal Cretaceous beds which form the terrace or encircling platform continue close up to the tower without any signs of disturbance. From the northwest and west vertical columns curving outward toward the base are seen, as well as some places which suggest a cross-section view of more or less radially disposed columns. White and yellow sandstone, apparently not greatly affected by heat and quite horizontal, were found near the top of the terrace, within less than a hundred yards of the base of the tower.

We examined Cabezon around more than three-quarters of its circumference (see plate 25 and figure 3), finding it very symmetrical, cylindrical in shape, with a number of exposures of the horizontal beds about its base and abundant evidence of vertical columnar structure, although the columns are nowhere so perfectly developed as in the Devils tower. We observed no direct contact between the igneous rock and the sediments as we did in other cases, and found the base of the tower and the surrounding sediments more obscured by talus and vegetation than was usually true.

In general the buttes of the Mount Taylor region do not rise above the former level of the lava cap, as indicated by the adjacent remnants of the lava-capped mesas. Cabezon is one of the two exceptions which we noted. It is evident that both Cabezon and Great neck rise above the level of Prieta mesa, although Cabezon is little, if any, higher than the top of Mount Taylor mesa to the west, while Great neck does not reach that level. Both buttes show features which are of special interest in connection with the unusual heights to which they attain. Thus, while the main portion of Cabezon is made up of dark, compact basalt, the talus slopes show much vesicular basalt, black, gray, and red in color, weathered down from the summit. The surface of the lava cap on Prieta mesa slopes upward toward the north, as if rising toward a large cone which formerly existed above the Cabezon butte, but which has been destroyed by erosion. Both buttes are of unusually large diameter, thus having a better chance for the preservation of their upward continuations in overlying lava flow or cones. The slopes at the base of Cabezon are strewn with fragments of a peculiar agglomerate, to be described in connection with butte number 3.

Number 2, Twin Peak (plate 26, and figure 4). As seen from a distance, this butte appears to be somewhat elongated in a north and south direction. It is surrounded by Cretaceous sands and shales, which were easily distinguished and which were apparently quite horizontal. Erosion has left the northern and southern ends of the butte somewhat higher than the middle portion; hence the name, "Twin Peak." This

butte was not seen at close range, but the sediments appear to continue well up toward the top of the neck at the northern end, indicating a more or less nearly vertical contact.

Number 3 (plate 27). This butte is rudely cylindrical in cross-section, is fairly flat-topped, of smaller diameter than Cabezon, and does not form so prominent a landmark as many of the others. A complete circuit of this butte was made for the purpose of examining it carefully on all sides.

On the eastern side the yellow and brown Cretaceous shales and sandstones are well exposed, and are seen to be quite horizontal and little affected by heat. They may be traced to within less than fifty feet of the butte at this point, but the precise contact is obscured. All sediments have been stripped away from this side of the butte down to the level of a hard sandstone layer, and this layer and its underlying beds

FIGURE 4.—*Twin Peak, showing horizontal Sediments well up Sides of Butte.*

are seen to be horizontal so close to the butte which rises above them that the appearance from a distance suggests a horizontal contact between igneous rock resting directly upon the sediments. A closer examination shows that in no exposure does the igneous rock rest upon the sediments; but large remnants of the sediments found well up toward the summit of this butte on other sides proves that the contact is essentially vertical.

The internal structure of the butte is fairly typical of the greater number of those examined. It is found to be composed of a peculiar agglomerate consisting of angular or somewhat rounded fragments of vesicular, generally reddish lava, loosely held together, often containing fragments of sandstone and shale, and shot through in all directions by great tongues or stringers of more massive columnar lava. The columns in this butte are often finely developed at right angles to the contact with the agglomerate, showing that the liquid lava was the last to be intruded. Doubtless in many cases there have been several alternations of the two types of activity. The agglomerate suggests a more or less explosive

FIGURE 1.—BUTTE NUMBER 3 FROM THE NORTHEAST

Top of number 5 in the distance. Mount Taylor mesa forming skyline beyond

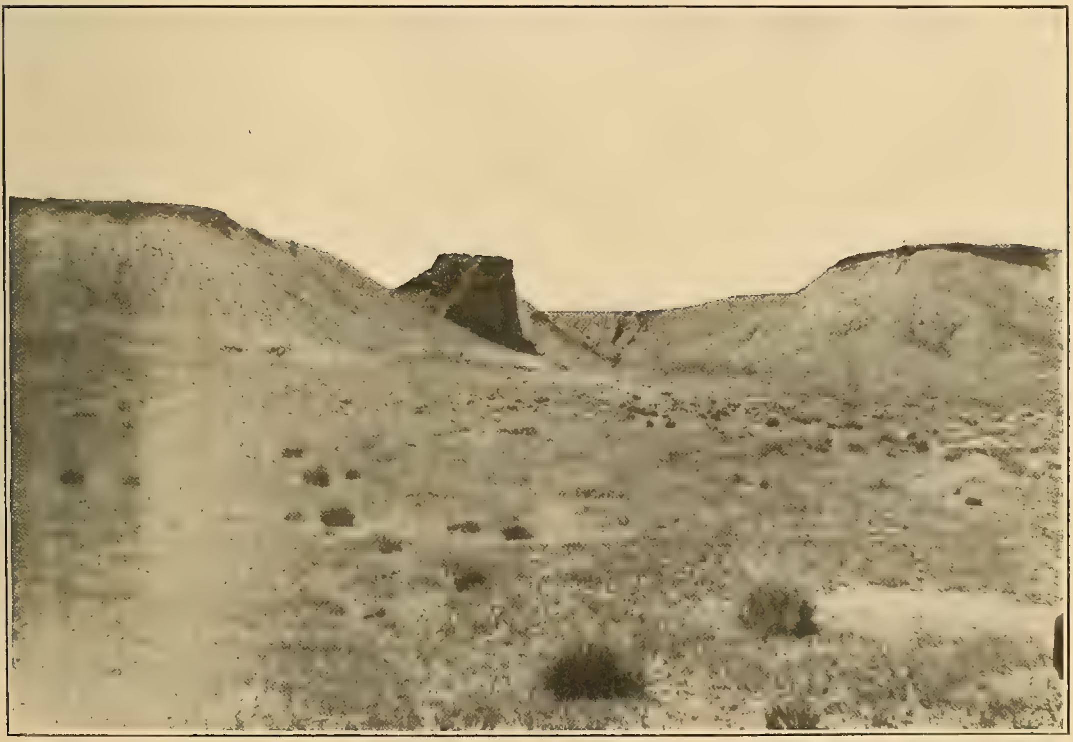

FIGURE 2.—BUTTE NUMBER 14, SOUTHWEST OF SALAZAR

Showing undisturbed surrounding shales capped by sandstone

BUTTES NUMBERS 3 AND 14

phase of volcanic activity. Both sedimentary and igneous fragments are often rounded and appear to have been churned up together. Distinctly bomb-like masses of lava are often seen. The sedimentary fragments vary in size up to three feet in diameter, and are frequently much baked on their outer surfaces. As a rule, no evidence of stratification is visible in the agglomerate, but occasionally distinct traces of rude bedding are made out near the side of the butte, as if during a somewhat quieter phase of the eruption an old conduit were filled up with the fragmental material which was not carried clear away from the exit.

Up through the great mass of agglomerate came the basaltic lava, apparently rising higher than the agglomerate in places and flowing over it. How much higher the lava reached is problematical. On the southeastern side is seen a splendid contact between the agglomerate and the lava, the line of contact running up the face of the butte to near the top,

FIGURE 5.—*Butte number 4, showing horizontal Sediments surrounding igneous Core, with vertical Contact exposed on south Side.*

and then becoming horizontal where the lava flowed out over the agglomerate, while the columns, being at right angles to the contact, are horizontal so long as the contact is vertical, but change to vertical where the contact is horizontal. In other places the columns are less regular.

At various points around this butte the sandstone was found in place well up the sides of the neck, while in the ravine the igneous rock could be followed down to much lower levels, leaving no doubt in the mind of the observer that the contact was essentially vertical, and that the sediments must formerly have enclosed the rudely cylindrical butte on all sides, having since been partly removed by erosion.

It should be noted that this butte and its enclosing sediments are found several hundred feet lower, both as to actual present elevation and as to stratigraphic position, than the Cabezon and Twin Peak buttes. There is seen to be no relation between the buttes. so far as absolute or relative elevations are concerned. Their heights and the part of the sedimentary series still found about them depend on the amount of destruction accomplished by erosion at each particular point.

Number 4 (figure 5). This butte resembles number 3 in being composed of both agglomerate and columnar basalt. A detailed description of the structural features of the different buttes would in most cases be essentially a repetition of that given above for number 3. Accordingly only critically important points will be specifically mentioned in the remaining descriptions.

The horizontal Cretaceous beds are well exposed about the base of number 4, and in some places well up the sides. This is especially true on the south side, where horizontal sediments are seen well up toward the summit, making a vertical contact with the igneous core of the butte.

Number 5 (plate 30, and figures 6 and 7). This butte is of special interest because of the unusually good exposures it affords. On the north-

FIGURE 6.—*Diagrammatic Sketch to show Relation of surrounding horizontal Sediments to igneous Core of Butte number 5 and the complex Structure of the Core.*

ern and western sides the yellow sandstones and shales are beautifully exposed and show practically no disturbing effect of the intrusion. Gullies have cut back through the sediments to the butte, ending abruptly against the more or less vertical wall of igneous rock. These give peculiar niches or alleyways, flanked on either side by steep walls of horizontal sediments, with a back wall of igneous rock formed by the side of the butte. The precise contacts are sometimes well shown, and are seen to be essentially vertical. The sediments are usually cut off square, without any evidence of disturbance whatever, but occasionally they show a slight dip away from the contact. In one place a distinct stringer or dike is seen running from the butte out into the sediments.

The upper part of the butte shows fair vertical columnar structure in places, and vertical columns are found well down the butte on one side

at least. Elsewhere the columns are curved and rather irregularly developed. Radially disposed columns appear to be shown in cross-section. On one side of the butte rudely bedded agglomerate is found, with vertical columns close by. In places the agglomerate is shot through in every direction with columnar and more massive lava, producing as complicated

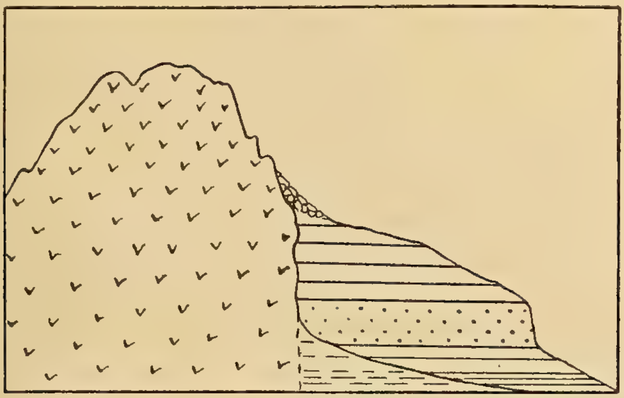

FIGURE 7.—*Cross-section showing Relation of horizontal Sediments to igneous Core of Butte number 5, western Side.*

a mixture of the two as one could well imagine. The lava is in part very vesicular, in part more dense. The accompanying text figure 6 is generalized from field sketches and photographs, and, while showing the general relations fairly well, indicates a much less complicated structure for the igneous core than actually exists. The sandstones near the contact with the butte appear somewhat more yellow than those farther

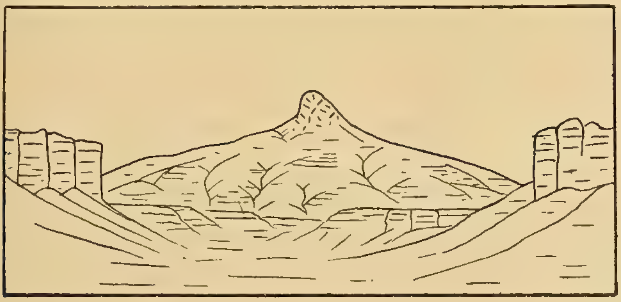

FIGURE 8.—*Cerro Cochino, showing igneous Core rising above surrounding horizontal Sediments.*

away, and are possibly a little firmer, suggesting some metamorphic influence of the butte. It might be that this induration has made the beds more resistant to erosion, in part accounting for the small zone of sediments often left about the necks; but the results of baking may not be so pronounced. In most cases it is hard to detect any metamorphism

whatever. The circular benches of sediments are more likely due to the protective action afforded by the central cores of igneous rock rising well above them and the accumulated talus of large lava fragments which are sometimes found about the bases of the towers.

Number 6, Cerro Cochino (plates 26 and 28, and figure 8). This butte is composed of a very large bench or terrace of the horizontal Cretaceous sediments, from the top of which rises a shaft of igneous rock. The right-hand butte shown in figure 21 of Dutton's report is evidently Cerro Cochino. We made no detailed examination.

Number 7 (plate 28). Southeast of the Mexican village of Salazar is a large butte surrounded by horizontal sandstones and shales. The butte appears to be elongated in a north and south direction, although we did not make a close examination. Just north of it, in the side of

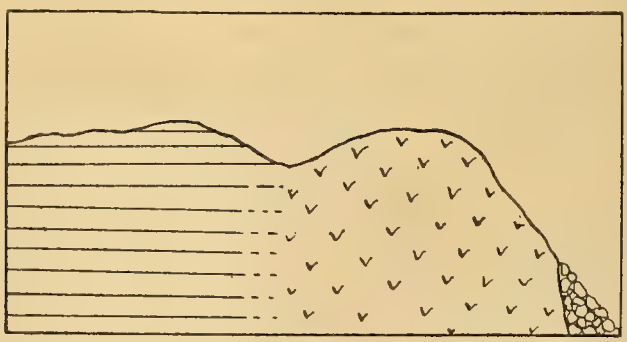

FIGURE 9.—*Cross-section showing Contact of horizontal Sediments with igneous Core of Butte number 8.*

Precise contact covered with wash.

Prieta mesa, there is evidence of a fault, the displacement being 75 feet or more, as nearly as we could estimate.

Number 8 (figure 9). This is a medium-sized butte showing fine columnar structure, the columns pointing in almost every direction, except that no good vertical ones were seen. The sediments have been stripped away from every side but the southeast, where they are seen making a vertical contact with the igneous rock of the butte almost to its summit. The beds remain horizontal. A small dike, a few feet in width, can be traced from the butte a short distance northward.

Number 9. This butte contains a large proportion of agglomerate, and as seen from a distance appears to be somewhat elongated in a north-south direction. Small hummocks are seen at intervals southward toward Great neck; these hummocks may be minor buttes similar to the larger ones, or remnants of a dike; it was not possible for us to visit them.

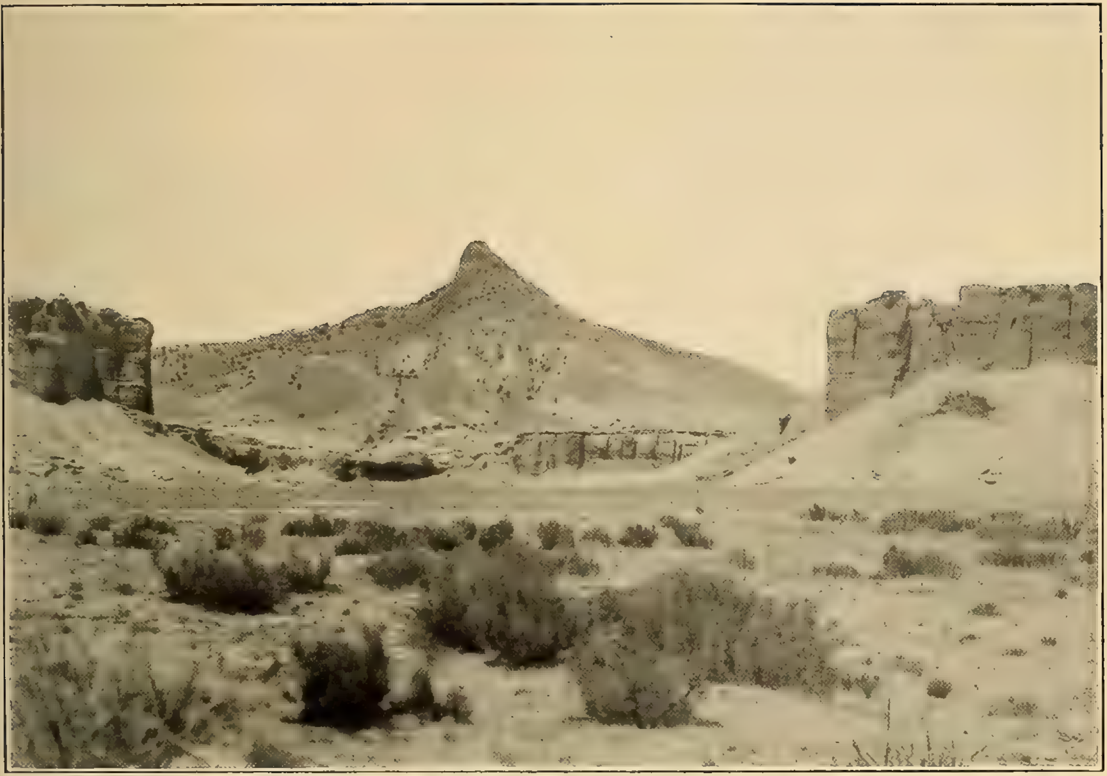

FIGURE 1.—CERRO COCHINO (BUTTE NUMBER 6) FROM THE WEST
Showing undisturbed sediments well up toward top of butte

FIGURE 2.—BUTTE NUMBER 7, IN THE SIDE OF PRIETA MESA
Showing undisturbed enclosing sediments

BUTTES NUMBERS 6 AND 7

FIGURE 1.—DIKE OCCUPYING FAULT FISSURE WEST OF SALAZAR

FIGURE 2.—BUTTE NUMBER 11 AND 12, ASSOCIATED WITH ABOVE DIKE

DIKE OCCUPYING FAULT FISSURE, AND BUTTES 11 AND 12

Numbers 10, 11, 12, 13. The relations of four small buttes west of Salazar are of special interest. A north-and-south dike (plate 29), from 2 to 4 feet in width, occupies a fault fissure, the evidence of faulting appearing where a somewhat massive sandstone meets softer sands and shales at the fissures. At one point the dike suddenly expands into a butte some 20 feet in width by 35 in length, composed of the peculiar agglomerate so often found in the large buttes, and of columnar basalt, the columns being irregularly curved. A short distance south is a much larger butte, also an expanded portion of the dike, showing beautifully curved basaltic columns more or less radially disposed (plate 29). From this point a branch dike seems to run off to the west, expanding into small buttes at two points. The first of these two buttes is composed in part of the agglomerate containing sandstone fragments, while basaltic columns are approximately horizontal on either side, showing a form

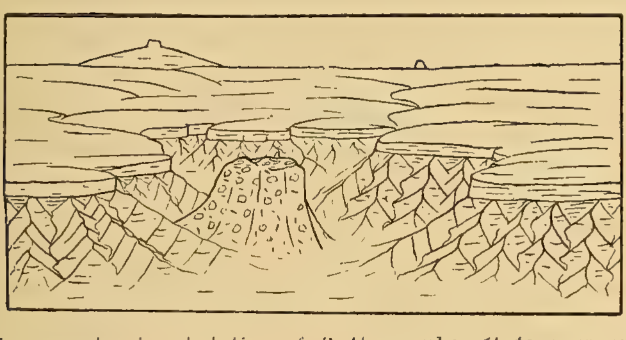

FIGURE 10.—*Diagram showing Relation of Butte number 14 to surrounding Sediments (Shales capped by Sandstone) and to other Buttes in the Region.*

transitional between dike and butte. It is clear that the buttes represent igneous rock which filled tubular conduits leading up through the sediments, just as the associated dike represents igneous rock which filled a fissure in the sediments.

Number 14 (plate 27, and figure 10). Southwest of Salazar is a butte, 75 or 100 feet in diameter, composed almost entirely of agglomerate which included large fragments of sandstone and shale. This butte is surrounded by horizontal gray shales capped by yellow sandstone. On three sides these beds rise practically to the present summit of the butte, erosion having etched out a semicircular depression about the immediate contact, leaving the butte somewhat isolated from the enclosing sediments. That the contacts about this rudely cylindrical butte must have been vertical is quite evident. The direct contact is occasionally still visible, the beds being bent upward in some places near the butte, but remaining horizontal elsewhere. Sedimentary rocks, well exposed, were traced all around the butte without discovering any indication of a dike.

Numbers 15 and 16. About a mile north of Great neck is a small butte which appears to be composed wholly of agglomerate, although its western side was not seen. One-third of a mile northwest of Great neck is another small butte composed of both agglomerate and beautifully columnar basalt, the columns being irregularly disposed.

Number 17, Great neck (plate 30). With the exception of Cabezon, this is the finest butte in the region. According to Dutton's report, it rises 1,800 or 1,900 feet above the valley and has a diameter of about 1,300 feet. Although that writer was unable to visit it, he reproduces a picture of it in his report.

On examination we found the greater part of this butte to consist of columnar basalt. As seen from the northwest, the columns in the main portion of the butte are vertical. Farther around to the west side the columns are vertical above, but curve outward toward the horizontal below. In other places the columns are more irregular. On the north side of the butte agglomerate and irregular basaltic columns are seen.

The summit of the butte presents features of some interest. There appear to be two horizontal layers of igneous rock lying on the columnar portion of the butte and forming a sort of double cap for it. Ascending the west side as far as the contact between the columns and the bottom of the lower layer, I was able to see that the latter consisted of a more or less decomposed, structureless sheet of lava, while above it came a thick layer of agglomerate full of good volcanic bombs and exceedingly vesicular lava. These features suggest that the upper part of this great butte represents its upward continuation, possibly into an overlying volcanic crater where successive layers of material spread out in the bowl of the crater, to be subsequently preserved in part, because of their position immediately above the resistant mass of the butte itself. In this connection it is noted that Great neck rises distinctly above the general level of Prieta mesa just east, although it is lower than Mount Taylor mesa to the west.

Other buttes. From near the summit of the west side of Great neck, one can count from 30 to 35 volcanic buttes, exclusive of the very small ones of those already mentioned. Dutton estimates that in the Mount Taylor region there are probably several hundred of these buttes exposed. Some of these he reports as being exposed in the sides of the great lava-capped mesa which formerly covered the Puerco Valley region, a complete section of a butte connecting with overlying cone and lava flow sometimes being secured. Several of the buttes which we saw from a distance appeared to be but partly exhumed by erosion along the side of the mesa, but we were unable to visit them to determine their exact rela-

FIGURE 1.—BUTTE NUMBER 5 FROM THE NORTH
Showing undisturbed surrounding sediments

FIGURE 2.—GREAT NECK, FROM THE NORTHWEST

BUTTE NUMBER 5, AND GREAT NECK

tions. At the northern end of Mount Taylor mesa the lava seems to show distinct bedding with a slight dip to the south, while just north is one of the buttes. The features strongly suggest a neck which was a conduit to a volcano, and the lava flows sloping away from that volcano, the cone itself having been removed by erosion.

Dutton has described in some detail a number of the buttes in other parts of the region. According to his descriptions, vertical columnar structure is not uncommon; evidence of repeated eruptions from the same vent is abundant; the buttes are often elongated rather than cylindrical, and the long axis may be prolonged in both directions by dikes. No evidence of recent flows is found in connection with the buttes. It appears, therefore, that there is a general uniformity of essential features in the buttes of different parts of the region. In minor details there is variety, some buttes being large, others small, with every gradation in size between the two extremes. Some are composed almost wholly of agglomerate, some almost entirely of basaltic lava, while others are intermediate in composition; some of the buttes appear nearly circular, others are more elongated, usually in a north-south direction; dikes are visible connecting two or more of the buttes, or extending a shorter distance north and south of a single butte, or appear to be wholly absent. But, as regards those features critically important in the present discussion, the relations are uniform and simple. The buttes are located in the lowlands produced by erosion, are not associated with lavas more recent than the main great lava cap which formerly extended out over them, have evidently served as vents for repeated eruptions, and show every gradation from buttes well stripped of enclosing sediments, through those showing more or less of the sediments making vertical contacts with the igneous rock, to examples just beginning to be exhumed from the walls of the mesa and which still connect with overlying cones and lava flows.

Possible Interpretations

A. As Remnants of Laccoliths or Sills

Can the buttes of the Mount Taylor region be interpreted as remnants of laccoliths or sills, all the overlying beds having been removed by erosion, as well as all the intrusive mass except a small more or less cylindrical shaft? Such an origin has been announced for the Devils tower, in Wyoming, partly because of its vertical columnar structure and undisturbed associated sediments. We have seen that many of the Mount Taylor buttes show vertical columnar structure, though never so perfect as that in the Devils tower, while practically all of them are associated

with undisturbed sediments. There is also noted a tendency for the columns to turn outward toward the base in the case of the Mount Taylor examples, another feature which allies them to the Devils tower. Agglomerate is abundant in the Mount Taylor examples, and is found in the lower part of the Devils tower. There are certainly features of strong resemblance between the buttes in the two places. In pointing out this resemblance, I accept Professor Jaggar's photographic and written descriptions of the Wyoming example, as I have not seen the tower.

To such an interpretation for the Mount Taylor buttes there appear to be serious objections. First, we should have to imagine hundreds of laccoliths or sills developing at all possible horizons in a series of sandstones and shales, either near the surface, which was at the same time covered with a flow of the same lava, or else in depth with long subsequent erosion and finally a surface flow similar to the material previously intruded.

We should have to grant, further, that erosion at various levels and at numerous places happened to be so nicely adjusted in every case that the overlying arched beds were invariably completely removed, leaving only the horizontal beds beneath, and that in some remarkable manner erosion always removed just enough of the intrusive mass itself to leave a rudely cylindrical tower, oval or circular in cross-section, resembling a volcanic neck. If the buttes are remnants of either laccoliths or sills, surely in all the examples studied there should be at least one which would show some trace of overlying sediments; one in some other stage of erosion than the penultimate; one which in some way bore distinct resemblance to a laccolith or sill.

Maturely eroded laccoliths or sills should show traces of the horizontal contacts between the base of the intrusive mass and the underlying sediments. The contacts seen in the Mount Taylor region were all vertical. It is true that the horizontal contact might be wholly concealed in one or even several remnants of laccoliths or sills, and that vertical contacts might occasionally be seen in such remnants where the intrusive mass cut across the bedding; but it is beyond probability that in so large a number of examples as have been studied in the Mount Taylor region there should be found no trace of horizontal contacts, but many vertical contacts, if the buttes were really remnants of laccoliths or sills.

The structure of the buttes makes the laccolithic or sill hypothesis inadmissible. They are sometimes composed wholly of an agglomerate indicating explosive activity, and at other times have numerous lava tubes running up through the agglomerate, showing repeated uprisings of the lava toward the surface. The agglomerate often contains good volcanic

bombs. Dense igneous rock is characteristic of intrusives, but the lava in the Mount Taylor buttes is often vesicular, sometimes extremely so.

Were laccoliths or sills so numerous in the region, we ought to find some of them shown in section in the sides of Mount Taylor mesa; yet nothing of this character has been observed there. On the other hand, good sections of volcanic necks still connecting with overlying cinder cones and lava flows have been described by Dutton, these necks bearing every resemblance to the closely associated but more completely eroded examples farther out from the mesa.

In view of the above facts, it would seem inadmissible to assign a laccolithic or sill origin to the Mount Taylor buttes; hence we must conclude that vertical columnar structure and undisturbed associated sediments are not safe guides in distinguishing between remnants of laccoliths or sills and volcanic necks.

B. AS REMNANTS OF SURFACE FLOWS

Can the Mount Taylor buttes be regarded as remnants of surface flows? This would explain the vertical columnar structure and undisturbed sediments as well as the vesicular character of the lava in places.

Again we meet the serious difficulty of being compelled to postulate an erosion which happened to leave several hundred more or less cylindrical towers of lava, but which failed to leave any larger remnants which could be readily recognized as undoubted flows. The great lava caps of Mount Taylor mesa and its outlying remnants, at a fairly uniform and distinctly higher level, are obviously not to be considered in this connection. The fact that no distinct lava-flow remnant has been observed among the great number of buttes seen in the erosion lowlands of the region is sufficient to negative the hypothesis here considered.

But there are other objections to the hypothesis. The buttes occur at different elevations above the valley floor as well as at different stratigraphic horizons. In order to interpret the buttes as remnants of flows, we must assume numerous flows at different levels, or else a single flow over a very uneven topography. But we have already seen that there is no evidence of any volcanic activity in this part of the district later than that which produced the great lava cap, and that this lava cap spread out over a surface of relatively faint relief.

Remnants of surface flows should show horizontal contacts with the underlying sediments, and only rarely vertical contacts where the lava flowed against some cliff or valley wall; yet no horizontal contacts were seen in connection with the Mount Taylor buttes, although the erosion of ravines is often favorable for the disclosure of such contacts if they

existed, while vertical contacts are visible about most of the necks and sometimes almost completely around them.

The structure of the buttes, as already described, indicates their function as conduits leading to some surface higher up, and is quite distinct from the normal structure of flows. The stringers and dikes, which sometimes run from the buttes into the surrounding sediments, are not normal accompaniments of surface flows. Sections of the buttes in the sides of Mount Taylor mesa exclude the flow-remnant hypothesis.

C. AS VOLCANIC NECKS

If the buttes of the Mount Taylor region are to be regarded as true volcanic necks, representing the material which remained in tubes or chimneys connecting with vents at some overlying surface, they ought to show certain critical features.

Being revealed only as a result of the removal of overlying cone and surface flows, volcanic necks ought to be found in the areas subjected to great erosion. They are essentially erosion features. We should expect them to occur in the valley lowlands and not on the adjacent highlands, especially if the highlands represented the former surface and were covered with portions of surface cones and flows not yet destroyed by erosion. Neither should the necks rise above the former level of the lava cap, as indicated by associated mesa remnants, unless, as might occasionally happen, the upper continuation of the neck into the cone were more or less preserved. The buttes of the Mount Taylor region occur only in the valley lowlands produced by erosion since the volcanic period, and seldom rise above the former level of the lava cap as indicated by the elevation of Mount Taylor and Prieta mesas. The exceptions noted have features which indicate that their upper continuation into the overlying cone are to some extent preserved.

Volcanic necks should often show evidence of repeated eruptions, both explosive and quiet. The different tongues or stringers of lava would show irregular columnar structure where various eruptions of different dates were represented; but where a single lava flow welled up to the surface and then solidified, the lava remaining in the conduit might show quite regular columnar structure. That part of the lava cooling deep in the conduit would have the surrounding sedimentary walls as the cooling surface, and the columns would therefore tend to develop a radial arrangement; but that portion of the lava nearer the top of the conduit would find a much more effective cooling surface in the free air above the crater, and the columns developing perpendicular to this cooling surface would be vertical. Passing downward, a point would finally be reached

where the cooling effect of the sedimentary wall would exceed the cooling effect of the more distant upper air, resulting in a change from vertical to radial columns. If the lava in the neck was continuous with a lava cone above, both being highly heated and the cone having a crater in it situated above the neck, there would result a vertical columnar structure in the upper part of the neck, the columns gradually curving outward and becoming radial farther down.* The vertical columnar structure would extend much deeper in necks of large diameter than in necks of small diameter. The buttes in the Mount Taylor region conform to these expectations quite closely. Many of them show evidence of repeated eruptions, with irregular columnar structure in the different lava tongues. Some are composed almost wholly of lava, with vertical columnar structure in the upper part, the columns curving outward and becoming radial farther down. The larger necks show the best vertical columns, while the smaller necks quite uniformly show an irregular or more radial arrangement. In many cases, of course, only the deeper portions of the smaller necks are preserved, the higher portions standing the best chance for preservation in the necks of large diameter.

Volcanic necks, continuing indefinitely in depth, should be exposed at any elevation or stratigraphic horizon below the former surface to which erosion happened to reach. The buttes of the Mount Taylor region are found at all levels, from the former upland surface down to the bottom of the present valleys.

The erosion of volcanic necks might occasionally show a limited horizontal contact due to irregularity in the walls of the neck, but most of the contacts exposed by erosion should be more or less vertical. All the contacts observed about the Mount Taylor buttes were essentially vertical.

Regarding the attitude of the sediments enclosing the necks, it would appear that they might reasonably be expected to remain practically undisturbed, if we admit the gradual enlargement of the vents from formerly insignificant apertures, as advocated by Dutton. Our own observations led to the conclusion that there were fissures in the region, many of which could not be detected without more detailed field study than we could make, but a few of which were more noticeable because they were opened and filled with lava, forming dikes which are still preserved, or else associated with differential movements developing faults which are sometimes visible in the mesa walls. Along these fissures were occasional vents, probably of exceedingly small diameter to begin with, where escaping volcanic material found its way to the surface. Con-

* I submitted the problem to Professor Wm. Hallock, of Columbia University, and am indebted to him for information on this point.

tinued explosive ejection through the most favorable of these vents resulted in their enlargement by the continuous detaching of fragment after fragment from the sedimentary walls of the expanding tube or chimney. Such a process would not tend to disturb the attitude of the surrounding sediments. It is true that a mass of lava over a thousand feet in diameter, thrust up bodily through horizontal sediments, could hardly be expected to leave those sediments horizontal. In the gradual enlargement of a vent from a few inches or feet to a thousand feet or more in diameter, by the progressive sapping of the surrounding walls, the sediments would be less apt to suffer disturbance, since fragments from the walls of the conduit would break off more readily than would great masses of sediments be flexed upward by the locally applied force. It is this latter process which appears to have been active in producing the volcanic necks of the Mount Taylor region. The horizontality of the beds associated with the Mount Taylor necks are therefore to be regarded as a normal feature.

Résumé

In conclusion, it appears that the various phenomena associated with the buttes of the Mount Taylor region accord perfectly with that hypothesis which interprets them as true volcanic necks, but do not admit of their interpretation as remnants of flows, sills, or laccoliths. Vertical columnar structure must be regarded as a normal feature in the upper parts of volcanic necks, as must also the lack of disturbance noted in the sediments about such necks. Inasmuch as the most conclusive evidence on which a laccolithic origin was ascribed to the Devils tower of Wyoming consisted of features which are very characteristic of the volcanic necks of the Mount Taylor region, and since the descriptions of the tower mention no features that might not occur in connection with a volcanic neck, the writer feels that the origin of the tower should be regarded as an open question until further field study affords evidence upon which a decisive answer may be based.

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STRATIGRAPHIC SUCCESSION IN THE REGION NORTHEAST OF COOK INLET, ALASKA*

BY SIDNEY PAIGE AND ADOLPH KNOPF†

(*Presented by title before the Society December 29, 1906*)

CONTENTS

INTRODUCTION

The facts to be presented here were gathered during the summer of 1906, while undertaking a rapid geologic reconnaissance in the region northeast of Cook inlet, Alaska.

REGION INVESTIGATED

Cook inlet occupies a broad indentation on the western side of the gulf of Alaska. The region explored is drained by two rivers—the first, the Matanuska, emptying into Knik arm at the head of Cook inlet; the second, Sushitna river, emptying into Cook inlet proper. Though portions of the region have been visited at various times in the past by Eldridge,‡ Mendenhall,§ and Martin,|| much of the area is unknown. A notable

* Received by the Secretary of the Society May 28, 1907.

† Introduced by Alfred H. Brooks.

‡ G. H. Eldridge: Reconnaissance in Sushitna basin, Alaska, 1898. Twentieth Ann. Rept. U. S. Geol. Survey, pt. vii.

§ W. C. Mendenhall: Reconnaissance from Resurrection bay to the Tanana, Alaska, 1898. Twentieth Ann. Rept. U. S. Geol. Survey, pt. vii.

|| G. C. Martin: Reconnaissance of the Matanuska coal field, Alaska. Bull. no. 289, U. S. Geol. Survey.

development of Jurassic and Tertiary sediments and the presence of workable commercial coal in such a remote district seem of sufficient importance to warrant the presentation of the following facts:

Scope of the Paper

An attempt will be made to give a brief statement of the stratigraphic succession in the area traversed. It should be stated that diverse parts of the field were covered by the writers respectively, and that the observations thus made were therefore in part supplemental. While the fauna of Mesozoic age was almost in its entirety collected in the region east of Chickaloon creek, the flora of the Kenai (Upper Eocene) was found on the lower Matanuska river and on Chickaloon creek.

Distribution of the Terranes

A glance at the map will show in a broad way the distribution of the several terranes. It may be seen that the boundary between the Tertiary and Mesozoic sediments trends northwest across Matanuska valley about 70 miles from tide water. The area mapped as granite was only studied along the margin, and other rocks may be included within it. Bordering this central granite mass on the western and northwestern margins is a series of slates and graywacke-slates; on the southern flank it is in part bounded by a narrow belt of mica-schist.

The oldest rocks of the region are probably represented by a series of crystalline schists comprising garnetiferous mica-schist and chloritic albite-zoisite schist. On the basis of petrographical similarity, they are correlated with the schists of the Yukon-Tanana region and tentatively assigned to a pre-Silurian age.

The next youngest rocks are a slate and graywacke-slate series, closely folded and of unknown thickness. No fossils have been found in them, so that their age is purely conjectural. They show, however, some resemblance to the rocks of the Sunrise series, which are regarded as of Upper Paleozoic age.

Middle Jurassic

The lowest rocks of determined age are Jurassic beds developed in the region of the upper Matanuska river and in the valley of Chickaloon creek and Talkeetna river. They have also been found as far north as the headwaters of Sushitna river.

These strata of Middle Jurassic age are divided into two series, separated by a pronounced unconformity. The lower series will be described first.

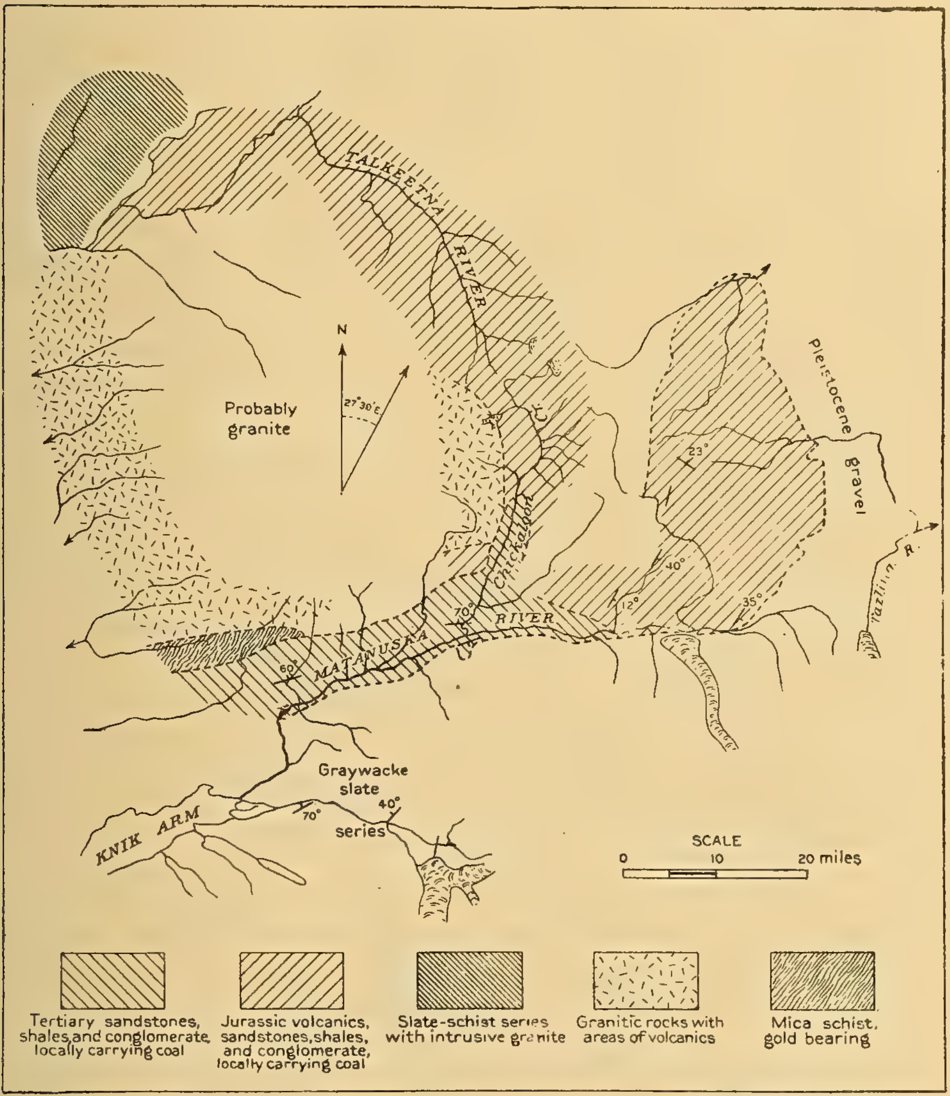

FIGURE 1.—*Geologic Map of Region Northeast of Cook Inlet, Alaska.*

Greenstones and related pyroclastics constitute the most characteristic portion of these rocks. Tuffs, agglomerates, and flow breccias form the great bulk of the greenstones, and intercalated flows of coarse amygdaloid are of frequent occurrence. Examination in thin-section shows that the greenstones and their ejectamenta are andesites of hyalopilitic and pilotaxitic textures, more or less thoroughly chloritized.

The thickness of this accumulation often exceeds 1,000 feet. The tuffs locally carry fragments of lignite, and at one point were found to contain marine shells in a fine state of preservation. The fossils were submitted to Dr T. W. Stanton, who reports in part:

"*Rhynconella.*	*Astarte* (?).
Lima.	*Protocardia.*
Pecten—smooth species.	*Pleuromya.*
Pecten—species of Vola type.	*Sonninia* (?).
Trigonia.	

"The Jurassic age of this lot is clearly shown by the form of the Trigonia and of the Ammonite (Sonninia ?). The general aspect of the fauna is that of the lower part of the Enochkin (Middle Jurassic)."

The greenstones and tuffs just described are transitional into an overlying series of graywackes, sandstones, shales, and subordinate conglomerates.

Several of these latter, of very diverse constitution, occur interstratified with seams of low-grade bituminous coal. In the northeastern part of the field several hundred feet of stream bluffs 100 feet high are composed of conglomerate consisting of various porphyries and white quartz pebbles in a gritty, coherent matrix.

The shales and sandstones of this series are in general barren of fossils, though Belemnites are rather common.

Inoceramus cf. *lucifer* Eichwald.	*Stephanoceras.*
Pleuromya.	*Oppelia* (?).
Pleurotomaria.	*Natica.*
Phylloceras.	*Sonninia* (?)—two species.

Doctor Stanton, who examined the fossils, states "that they may be referred without question to the lower part of the Enochkin formation as it occurs at Snug harbor," on the west coast of Cook inlet.

The beds are usually lying in monoclinal attitudes, broken by block faulting. Whatever folding is shown is, with one exception, of an open character. Evidence, however, of severe internal disturbance, such as the frequence of faulted pebbles in the conglomerates, is abundant, and shattering and minor faulting are widespread.

The series of rocks just described are separated from those next higher in the column by an important unconformity. At one point sandstones introduced by a thin basal conglomerate were found resting on the eroded edges of the Lower Middle Jurassic greenstones. The absence from the younger rocks of the profound shattering and shearing characteristic of the older rocks, and the strong discordance in their respective strike lines,

amounting to nearly 90 degrees, is strong evidence of this unconformity in portions of the field where direct contacts are not observable.

The overlying younger series forms a continuous stratigraphic succession of younger Middle Jurassic and of Upper Jurassic rocks. They consist largely of soft blue shales locally carrying fossiliferous limestone nodules. With the shales are associated various sandstones, often of loose coherent texture and containing great multitudes of Aucella. Interstratified beds of andesitic tuff, containing Belemnite remains, and hornblende-biotite arkose are also found. In the eastern part of the field stream bluffs reveal a curious interdigitation of lenses of cross-bedded sandstone carrying Aucella, of shale beds, and of coarse conglomerate lenses. Solitary water-worn boulders are found embedded in the shale lenses. These various characteristics are held to belong to an ancient delta deposit. In harmony with this interpretation is the fact that the Aucella characteristic of these rocks is often found in soft sandstones interstratified with sandstones inclosing abundant carbonaceous fragments.

At the head of Matanuska river the upper horizons of the shale become strongly calcareous and there show pronounced ripple-marking.

The fauna of the above succession of rocks is as follows:

Cadoceras sp.	*Aucella* cf. *bronni* Rouiller.
Pleuromya.	

The fossils indicate faunas of both the upper part of the Middle Jurassic and of the Upper Jurassic. The former is the Cadoceras zone of the west shore of Cook inlet, while the latter is the Aucella bronni zone of the same region.

It is interesting to note that the Upper Jurassic rocks of the Matanuska region, which are faunally allied to those of the Naknek formation on the west coast of Cook inlet, show a certain lithologic similarity in the presence of interstratified tuffs and arkose.*

On the headwaters of Sushitna river is a notable accumulation of conglomerate. Perpendicular cirque walls cut in it reveal a thickness of not less than 1,100 feet. Sandstone layers show it to be lying in horizontal attitude. The conglomerate, especially in its upper horizons, consists exclusively of large, well-rounded boulders of augite-andesite and very fresh hornblende-biotite-quartz monzonite imbedded in a tuffaceous matrix. Sheets of lava are intercalated in the conglomerate. The stratigraphic relations of this deposit were not seen, but on lithologic reasons it is corre-

* T. W. Stanton and G. C. Martin: Mesozoic section on Cook inlet and Alaska peninsula. Bull. Geol. Soc. Am., vol. 16, pp. 391-410.

lated with the Naknek (Upper Jurassic of Cook inlet), at the base of which a very similar accumulation occurs.

Lower Cretaceous

Rocks of Lower Cretaceous age are represented mainly by but a single formation—a massively bedded limestone, 300 feet thick, which overlies the Upper Jurassic rocks conformably. The limestone is very finely saccharoidal in texture and white in color. A characteristic feature is its strong, fetid odor on fresh fracture. The age determination of this limestone is based on the presence of *Aucella crassicollis* Keyserling, obtained by Mendenhall. It may thus be seen that the rocks from the upper part of the Middle Jurassic through the Lower Cretaceous are in conformable succession.

Tertiary

The next youngest rocks of the region are of Upper Eocene (Kenai) age. They are a series of shales, sandstones, and conglomerates containing workable seams of high-grade bituminous coal of a maximum thickness of 17 feet.* A section exposed in Castle mountain shows 1,000 + feet of conglomerate at the base, overlain by sandstones and shales. At least 3,000 feet of these sediments were observed in a locality on Chickaloon creek.

The nature of the relations of these rocks to the Mesozoic series is yet in doubt. There are reasons, however, for believing that they overlie them unconformably.

No marine fossils have been found in this series, but floral remains, rather poorly preserved, are at times quite abundant. Dr F. H. Knowlton reports the following forms:

Sequoia langsdorfii (Brgt.) Heer.
Ficus ? grönlandica Heer.
Magnolia inglefeldi Heer.
Populus artica (?) Heer.
Rhamnus eridani Heer.
Viburnum sp.; cf. *V. nordenskiöldi* Heer.
Taxodium distichum miocenum Heer.
Taxodium tinajorum Heer.
Paliurus colombi Heer.
Fruits, cf. *Leguminosites op.*
Age, Kenai (Upper Eocene).

Overlying the older rocks is a series of nearly horizontal lava flows, basaltic in character. With their tuffs and breccias they attain a thickness of 1,000 feet. They are definitely known to overlie fluviatile conglomerates of post-Lower Cretaceous age, and probably rest on the Kenai so that their age is Middle Tertiary or younger.

* G. C. Martin: A reconnaissance of the Matanuska coal field, Alaska. Bull. no. 289. U. S. Geol. Survey.

The most recent deposits of the area are Pleistocene stream and glacial gravels. This formation is most extensively displayed near the head of Matanuska river, where the present stream gorge has cut through 300 or 400 feet of glacial gravels.

Intrusive igneous Rocks

In addition to the stratiform volcanics of Middle Jurassic and Tertiary ages, igneous rocks of intrusive character are abundant in certain parts of the region. Of these diabase dikes and sills are widely prevalent, attaining a maximum thickness of 500 feet. They are intrusive into rocks as late in age as the Kenai.

The granular plutonics making up the central mass of the Talkeetna mountains, however, possess far wider interest on account of their connection with problems of great geological significance. They are chiefly quartz-diorites carrying orthoclase, and are intrusive into rocks at least of Lower Middle Jurassic age. They are thus contemporaneous with the enormous batholithic intrusions of the late Mesozoic, which affected the entire Cordilleran region from the strait of Magellan to the Seward peninsula, in northwestern Alaska.*

Summary

The rocks of the area investigated range in character from garnetiferous mica-schists of pre-Silurian age to unconsolidated Pleistocene stream and glacial gravels. The region, however, is chiefly noteworthy on account of the extensive development of marine Jurassic strata and the presence of Upper Eocene fresh-water sediments carrying thick seams of bituminous coal.

The stratigraphic column may be summarized as follows:

	Feet
Pleistocene.—Stream and glacial gravels.	
Unconformity.	
Post-Eocene.—Basaltic lavas and pyroclastics	1,000 +
Upper Eocene.—Kenai formation: Sandstones, shales, and conglomerates, with coal seams	3,000 ±
Unconformity (?)	
Lower Cretaceous.—Limestone	300
Conformity.	

* A. C. Lawson: The Cordilleran Mesozoic revolution. Journal of Geology, vol. i, p. 579.

A. H. Brooks: The geography and geology of Alaska. P. P. 45, p. 250, U. S. Geol. Survey.

	Feet
Upper Jurassic to Upper Middle Jurassic.—Sandstones, shales, conglomerates, tuffs, and arkose	2,000 ±
Unconformity.	
Lower Middle Jurassic.—Meta-andesites and pyroclastics, graywackes, sandstones, shales, and conglomerates	2,000 ±
Unconformity (?)	
Upper Paleozoic (?)—Slates and graywacke-slates.	
Unconformity (?)	
Pre-Silurian (?)—Garnetiferous mica-schists and chloritic albite-zoisite schists.	
Intrusive quartz-diorites.—Intrusive into Lower Middle Jurassic rocks.	

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LATERAL EROSION ON SOME MICHIGAN RIVERS*

BY MARK JEFFERSON

(Presented by title before the Society December 28, 1906)

CONTENTS

INTRODUCTION

The southern part of the lower peninsula of Michigan is deeply coated with drift. The drift is often very homogeneous and but moderately interspersed with boulders. Toward the shores of lakes Michigan and Erie the drift is covered by fine lake clays, representing the floors of glacial lakes Maumee, Chicago, and their contemporaries. In this drift the rivers of the region have carved winding valleys between grassy bluffs, and themselves follow courses yet more winding on the flood-plain floor. Rock is rarely encountered, being buried too deeply. The border of the flood-plain under the bounding bluffs is quite irregular in plan when mapped, but is habitually scalloped in curves concave toward the river and of radius of curvature little greater than that of the neighboring meanders. Occasionally such curves adjoin, separated by sharp reentrant cusps. From 5 to 10 per cent of the bluff is bare of grass or trees—a steep slope of naked clay, as shown in the picture.

* Printed with the permission of the Geological Survey of Michigan.
Manuscript received by the Secretary of the Society June 3, 1907.

These bare strips, or "scaurs," as they are called in Scotland, lie at points where the meandering stream is now close to the valley wall, undermining it and causing it to cave and slip. Such points of contact between stream and bounding valley bluff may often be seen alternating to right and left in a view down valley, the up-valley aspect being wholly of grassy slopes. This is because the downstream migration of meanders causes a constant attack on the up-valley side of reentrant cusps, which are therefore the especial site of scaur, while the downstream side of the same reentrant watches the stream that once bathed its foot draw steadily away—a process admirably described by Davis. Valleys like this are typical of Michigan south of the Grand-Saginaw valley. Results of the

FIGURE 1.—*Scaur on the right Bank of the Lower Rouge.*

The river carries off creeping waste as fast as it falls, and the bank retreats.

uniform softness of the material in which they are cut are the rapidity with which they are made, the tolerable grade of their course, and the youthful slopes by which their flood-plains are everywhere bounded.

The topographic sheets of the U. S. Geological Survey are not usually accurate enough or detailed enough to show the character of these valleys or even the meandering of the streams that carve them, and the topographers have not recognized the existence of these forms. It is appropriate to their slight recognition that what I have called scallops in the bluff have no accepted name among writers on the subject. The sheet

for Ypsilanti, Michigan, however, shows the forms referred to in unusual detail, admirable scaurs occurring at the two points where the road toward Rawsonville on the left bank comes nearest to the river less than 2 miles from town. As scaurs are but slopes too steep for vegetation, the character of the vegetation is an important element in their occurrence. In general, the larger the growth, the stronger the root, the better the slope resists slipping, even when the foot is actively undermined. A grassy slope begins to break up as soon as the foot is washed by a stream, but a slope overgrown with shrubs resists much longer. One in trees is very resistant. Such a one occurs on the right bank of the Huron river about 2 miles southeast of Ypsilanti. The trees are well grown and well enough rooted to carry the ground with them in great blocks 20 by 30 feet, as they incline, some one way, some another, on their uncertain footing. Rents between the blocks afford basins that fill with every rain, until last year the inclination of the trees and lack of parallelism in their trunks was more noticeable than any cracking or slipping of the earth. The strain has become too great for them, and the slope will before long become bare. Had it not been for the trees, the slope would have been bare long ago.

The abundance of stripped bluff, or scaur, must vary with the development of the valley. A young stream has its whole bank in scaur. As scrolls of flood-plain develop on either hand the bluff above assumes a moderate angle of slope and begins to grass over. With a wide flood-plain comes a general grassing of the bluffs. The spots of stripped bluff are survivors of an earlier condition. As the scaur has its foot consumed rapidly by the stream while the grassy bluff is most stable below, steepness is almost as characteristic of scaurs as their bareness. From these considerations we may expect much inequality in the extent to which scaurs occur along streams, yet in a sufficient number of examples we should expect to find as many on one side as the other.

The author's attention was first called to scaurs on the lower Rouge in 1903, when, with Mr Isaiah Bowman, he counted their occurrence to ascertain what proportion of the valley was now subject to the widening process. We found this to be 10 per cent; but Mr Bowman at once noticed that two-thirds of them occurred on the right-hand side of the river, and this uniformly for many miles. He suggested the deflection due to terrestrial rotation as a possible explanation. It has long been believed that streams should show some tendency to bear to the right from this cause. It has not usually been possible to show that this tendency has perceptible effect. A note was published in *Science* for January,

1904,* giving the facts and our inference. Of course the test of such a theory was to examine other streams flowing in other directions. This has now been done. The Michigan Geological Survey—Dr A. C. Lane, Director—has borne the expense of transportation incurred in the course of the work, the results being published here with Doctor Lane's permission.

There is certainly system in the behavior of the rivers examined, but the effect can not be ascribed to rotational deflection. It seems rather to point to secular tilting of the land.

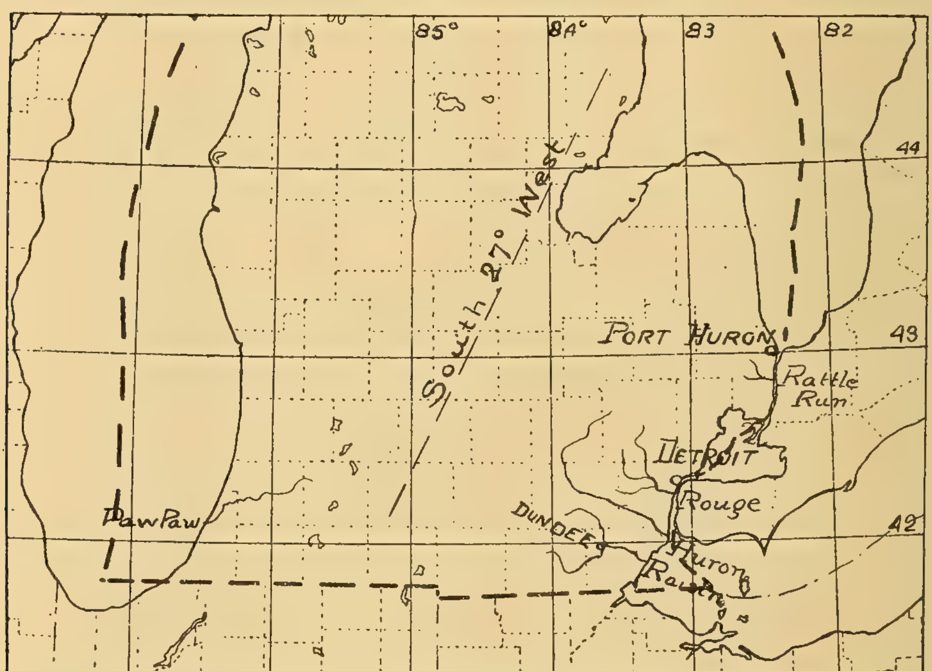

FIGURE 2.—*Rivers described in this Paper.*

The rivers studied are the Rouge, Rattle run, Huron, Raisin—all in the old basin of lake Maumee and drawing their waters from the morainic country to the northwest—and the Paw Paw, in an old glacial drainage line on the western border of the state. All are shown on the map.

River Rouge

The river Rouge enters the Detroit about 6 miles below the city of Detroit, taking its name from the "yellow," muddy color of its water. At Dearborn, about 8 miles from the mouth, the lower Rouge enters, and

* Page 150.

a little over a mile from there is the junction of the middle Rouge and the North branch. The lower Rouge flows east and east by north for 17 miles before meeting the main stream; the middle Rouge is about 20 miles long, half of this an east-southeasterly course on the old lake floor. The part of the North branch examined flows mainly south for 6 miles by the road from Sand Hill to the junction with the Middle branch. By the river the distance would be three times as great. All three branches are represented on the Wayne, Michigan, sheet of the U. S. Geological Survey topographic map, where the meanders are for the most part omitted, as may be seen by comparison with the sketches here given.

FIGURE 3.—*Flood-plain, Meanders, and Scaurs on the Lower Rouge.*
The area indicated is in Wayne county, Canton township, sections 25 and 26.

LOWER ROUGE

This stream has an ideal valley for the study of scaurs. The country has few trees, is level but for the 15-foot bluffs bounding the flood-plain. The river is filled with water every spring all across the valley, taking then a width of 500 feet, but dwindles in summer to a mere trickle of water that may be easily jumped across anywhere. The bed on which the stream flows, in mean stages, is 15 to 20 feet wide. Regardless of width, this branch of the river is never clear. Scaurs are always in view on looking down valley; rarely on looking up. An electric railroad runs beside, giving easy access to every part. The behavior of the stream in its valley is typically shown in the sketch map of a mile of its course about two miles west from Wayne. The photograph, figure 1, was taken in this neighborhood. The scaurs are uniformly 10 per cent of the length of each bluff. Three-quarters of them occur on the right-hand border of the flood-plain.

The average length of a scaur on the right valley bluff is 72 paces, on the left 47. On the right there are, on an average, 3 scaurs to a mile; on the left, 2.4. Here is a reasonable persistence in behavior. However we look at it, more work is being done on the right bank than on the left. The number of scaurs is greater, the length of an average scaur is greater, and the total amount of scaur is greater. The figures concerning the two stretches of middle course have been published in *Science*. The measures on the lower course are due to the courtesy of Mr Isaiah Bowman, of Yale University, and Mr Darrel H. Davis, of the Central High School, Detroit, assisted in obtaining the figures for the upper course.

Scaurs on the Lower Rouge

Course.	Distance, miles.	Paces of scaur.		Paces of flood-plain.	Percentages of bluff in scaur.	Percentages of scaur on the right.
		Right.	Left.			
Upper course...	3.3	469	140	5,601	5	77
Middle course..	2.6	653	357	4,126	12	64
Middle course..	4.1	978	591	6,406	12	62
Lower course...	3.3	1,082	137	5,810	10½	89
	13.3	3,182	1,225	21,943	10	72

Middle Rouge

Near Dearborn the Rouge is 30 to 50 feet wide, and has cut its bed about 8 feet below the flood-plain, which in turn is 16 feet below the country about. The river here is muddy as usual, but after passing the junction with the North branch the bottom can be seen, after heavy rains of the previous week. This branch has water as clear as the Huron. Generally speaking, the bluffs for the first 5 miles were wooded, and scaurs were rarely observed, only 2 per cent of the whole length of bluff, which may have something to do with the clearness of the water. Here,

Reach.	Paces in scaur.		Distance, miles.	Percentages of bluff in scaur.	Percentages of scaur on the right.
	Right.	Left.			
Lower reach	197	140	6	1	59
Middle reach	735	49	6	3	94
Upper reach	76	110	4½	1	41
	1,008	299	16½	2	77

as on the Huron, tree roots hold the bluff, and only evident cracks in the grassy slope mark spots that would be scaur on an open country stream; but the way the river holds to its right bluff is phenomenal. It is not exaggerating to say that it is almost always nearer that side than the

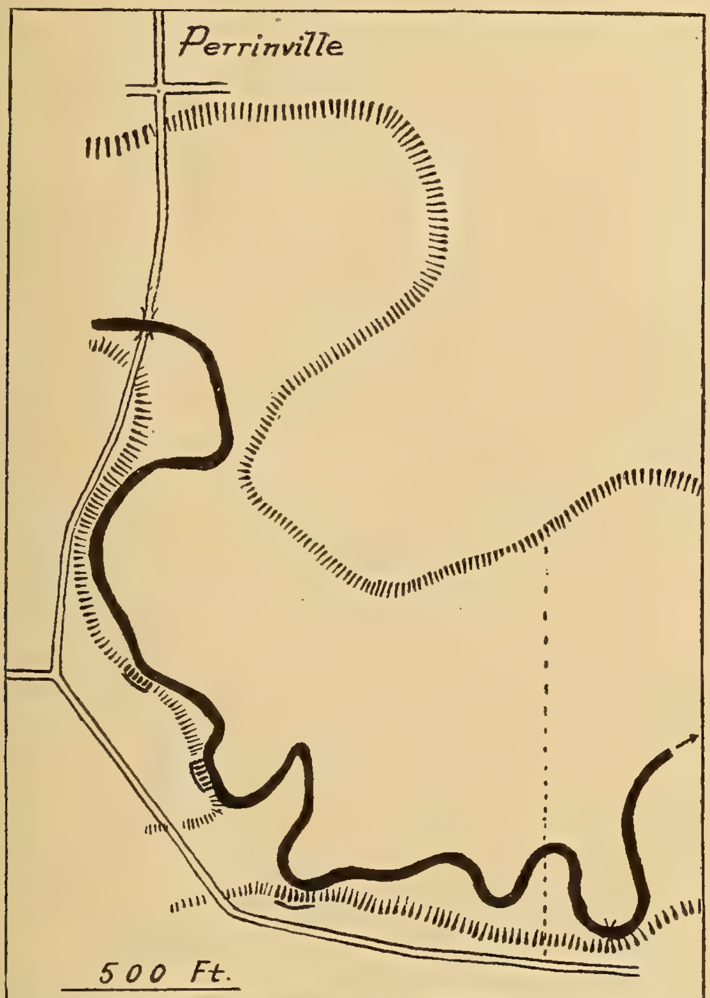

FIGURE 4.—*The Middle Rouge.*

The area indicated is in Wayne county, Nankin township, sections 2 and 11. The stream is shown clinging to the right bank.

other; that its meanders toward the left rarely take it half way across the plain. There are very few scaurs of bare clay from top to bottom, such as prevail on the lower Rouge. Here we more commonly find bare clay at top and bottom, with the ground between grassed over and grown up with bushes or trees. Beside this, which was counted for scaur, there were many times as much strong slope with river close beneath and with

signs of slipping that was not counted. The count extended 16½ miles along the river, to a point about 3 miles east of Plymouth, all on the ancient lake floor.

Pacings made by Mr Davis and the author in October, 1905. The scaurs on the right average 39 paces long; on the left, 37. On the right there are not quite two to a mile; on the left, one to two miles. For one space of four miles there were no scaurs on the left. Though the proportion of scaur is about the same here as on the lower Rouge, there is much irregularity in its distribution. The way the river keeps to the right, even when not making scaur, is shown fairly typically on the sketch here.

It has the same tendency to the right side of the valley, even in that part of the upper valley where scaurs preponderate on the left (41 per cent of all on the right). The shortening of the scaurs goes well with their lessened frequency, their lesser total length, and the clearer water of the stream. It is less actively widening its valley than the lower Rouge. It does not hold less strongly to the right (south) side.

North Branch of the Rouge

This part, called on the map the Rouge, is deeply cut into its plain—more than 10 feet, we estimated, all along its course, and at times as much as 15. It does not flood the whole of this plain, which is not, therefore, a true flood-plain; yet there are points 15 feet above ordinary water where deposits of sand had been left the previous spring, though only in narrow strips.

The writer has twice seen the lower Rouge cover its plain from bluff to bluff—a thing that certainly never occurs on the North branch now. For this reason this stream is not comparable to the others. It is not widening its flood-plain. Although it was examined along a distance of more than 20 miles, true scaurs were entirely wanting. One patch of 75 paces was mapped as scaur at a point where a tributary gully joins the main stream in a long stretch of what may be called "dead" scaur, enlivened here by the cutting of the tributary. By "dead" scaur is meant bluff descending steeply from the upland to the flood-plain of a river, with cracks in the ground, landslips, and trees tipping out of the vertical, though the whole face is fairly well grassed and not a continuous slope of bare earth like the true scaur. Attention has been called to this sort of thing in describing the middle Rouge. What was counted for scaur there was admittedly different from the scaurs of the lower Rouge, but it was all fairly active. On the North branch everything was noted that

had the water running close at its foot. Perhaps a third of this was actively slipping and broken. The surface was uneasy in all of it, but two-thirds of it was such as was not counted at all before.

Eight per cent of the course is bluff close to stream, 40 per cent of this on the right and 60 of the left. The average length of a scaur on the right is 170 paces; on the left, 180. Disorder takes the place of system; flood-plain is gone; scaurs are gone. Steep bluffs are there in varying percentage—now right, now left.

The plain is a terrace beneath which the Rouge has incised its course. The water is clearer than the lower Rouge, muddier than the middle Rouge. The river does not cling to either bluff and its course is nearly south. An interesting item revealed by the U. S. Geological Survey's mapping is that the 600-foot contour is crossed by the lower Rouge 3 valley miles from Dearborn, where the streams unite, by the middle Rouge 5 valley miles, and by the North branch 8½ from the same point. The surface of the country is near the same level at the three points, but the North branch has only half or a third as much fall as the others, being already cut to a much lower grade. It is not actively deepening its course; neither is it cutting actively sidewise.

Bluffs close to Water on the North Branch of the Rouge

Bluff paces.		Miles.	Direction.	Percentages of bluff close to stream.	Percentages of close bluff to the right.
Right.	Left.				
660	550	5.4	South-southeast	6	54
80	420	4.4	South	3	16
830	1,400	4.4	Southeast	13	33
370	280	2.8	South and southeast	6	57
325	775	2.8	South	10	29
620	0	1.1	South	13	100
2,885	3,425	20.9	South	8	40

Rattle Run

This is a branch of Pine river, 60 miles northeast of the Rouge, near Port Huron. A length of about three miles upstream from the mouth was examined by a student of the author, Mr A. E. Parkins, now of the Holland High School. The flow in this part of the stream is to the north-northeast. It is typical open flood-plain, 5 per cent of its length in scaur and another 10 per cent in active slip, but fairly grassed, 64 per

cent of the scaurs being on the right bank and 92 per cent on the slipping bank. Mr Parkins' map, with sketched contours, shows how the stream in crowding to the right has captured Shin creek and then occupied a portion of its old channel, for it appears evident that the two outlying terrace islands in the center represent a former extension of the upland

FIGURE 5.—*Rattle Run, near Port Huron.*

Showing the strong tendency to the right that has led it to capture Shin creek and occupy a part of its valley.

cusp from the south, which must then have had Rattle run on its left and Shin creek on its right. Rattle run has invaded Shin Creek valley at two points, the distance between them suggesting that it was the work of two successive meanders of the run. It is of interest to compare with this the Huron at the point of capture described by Bowman. The Huron swung to the left in a meander that captured Oak ravine, as

shown in his map, page 327. A little below, not shown on his map, another swing of the Huron to the left has almost captured Willow run, leaving only a low ridge dividing the flood-plains. From the point of view of lateral erosion it is of interest that the Huron, twice swinging to the left, *almost* invaded a neighbor valley; Rattle run, swinging to right, actually did it. Mr Parkins' measures are: Total length of both bluffs, 5,470 paces; scaur to right, 231; to left, 31; slipping bank to right, 1,034; to left, 86. The pacing was done in September, 1906.

Huron River

The Huron was examined from Ypsilanti to New Boston, a distance by the river of about 20 miles. The bluffs are commonly wooded and stand well. True scaurs are infrequent. The note book containing details has been lost. It is, however, remembered that, counting scaur and slipping bank together there was about two-thirds on the right bank. Of the true scaur there was slightly more on the left. The proportion of slip in the valley was not ascertained. The Huron does not completely flood its valley like the lower Rouge, but does inundate broad strips on each side every year. It is in dry weather a fairly clear stream and flows to the south-southeast.

Raisin River

The Raisin runs to lake Erie parallel to the Huron, about 16 miles to the southeast of it, on the same lake plains. It has two chief arms—the Saline on the north and the Raisin on the south—that meet at Dundee. Examination has been confined to these two branches. This region is essentially a coastal plain, with parallel, consequent drainage. Thus Paint creek (Stony creek) rises between Ann Arbor and Ypsilanti and flows all the way to lake Erie, never more than a few miles distant from the much larger Huron. The Raisin has developed more complexity. The branching above Dundee has the appearance of having arisen from the capture of rivals and neighbors on right and left.

There is an upper course to the Raisin that is fairly consequent in course, but the two branches referred to join nearly head on at a strong angle to the trunk below, the Saline coming from the north, the Raisin from the south-southwest. Along this part of the course of the tributary Raisin and near that of the Saline, Leverett locates the shore of lake Warren, running north-northeast, just east of the southern branch. It could hardly fail to guide the river in that direction, and seems to fully account for its deviation from consequent flow. Where the beach passes

the north branch (Saline), however, it is placed to the west. It was not observed in the field, attention being given to the river, its flood-plain and bluffs; nor did the observer have it in mind until it was brought to his attention at Milan. That the map is correct in representing the Warren shore as west of the Saline between Dundee and Milan is shown by the disappearance of flood-plain for 4 or more miles east of Milan, probably because the river crosses the beach here. Here there is no distinct valley between bluffs, only 8-foot side walls to the channel, and scaurs are wholly wanting, or, if one likes, the bank is all scaur on both sides. A little west of Milan reappears the open flood-plain. The extra depth of material to be cut through here seems to have delayed the river in developing its valley, so that it is intrinsically younger in form at this place. Here flood-plain will be developed later. From this point to Dundee 6 per cent of the bluffs are in scaur, mostly bare and typical, and 77 per cent of this is on the left. The river flows about southeast and floods its plain strongly, as is seen by driftwood and sand deposits on the grass. Measurements were made September 6, 1906. Of perfect scaur there were 731 paces, 576 to the left and 155 to the right, 79 and 21 per cent respectively. Of slipping bluff there were 335 paces, 250 on the right and 85 on the left, 75 and 25 per cent. The whole distance is called 9 miles by the valley, with 16 scaurs on the left, averaging 52 paces long, and 7 on the right, averaging 34 paces each—a little less than two to the mile on the left and less than one on the right. The river consistently inclines to the left; total scaur, number of scaurs, and length of individual scaurs all point the same way. It was observable in following the valley that even on the flood-plain the river held over to the left side of the valley. Possibly an outlying ridge of the Warren shore restrains it on the eastern side, but this should be looked for in the field. For about 3 river miles west of Milan dead scaurs are noted, 1,062 paces on the left and 857 on the right, 56 and 44 per cent respectively. There were no bare scaurs, the bluffs being much overgrown with trees and the stream as sluggish as if there were a dam at Milan. It was not followed further.

For the last three-quarters of the northeasterly part of the course of the south branch, or Raisin proper, it meanders strongly and bears hard to the right, being apparently held from a consequent course to the southeast by the Warren beach. This stretch measures about 20 miles by the bank. Ten miles of it were paced, from Dundee to the highway bridge near Petersburg, where the general course is to the northeast. Scaurs are frequent, forming about 15 per cent of the bluff in till about 25 feet

high; 69 per cent of them are on the right. In almost every case the downstream end of the scaur is absolutely bare; then farther up it has patches of slipped sod on it; then grass and trees, with occasional breaks showing the bare ground, and finally perhaps a well grassed slope, at the bottom of which is naked clay. This accords perfectly with the sweeping downstream of a meander system that Davis has described in the paper referred to. The upper part of the scaur is grassed simply because it is older. The same thing has been observed at other points.

In the seven cases of the sort that occur here 42 per cent of the scaur was bare—that is, of an average 462 paces of length the lower 193 were bare, the last 268 grassed over. The actual pacings are, naming the lower part first: 100–773, 468–135, 200–133, 195–425, 186–44, 30–70, 175–300.

In no case was a bluff counted as scaur unless it showed active movement downhill. Mr Charles C. Colby, instructor in geography in the State Normal College, made independent pacings and estimates of points of beginning and ending. His results agreed with the writer's within 1 per cent. Only 37 per cent of the naked scaur was on the right, but the grassed part is properly included in the count. The results are very consistent. Taking them in three groups, they are:

Scaurs.	Length of scaur in paces.		Per cent of scaur on right.
	Right.	Left.	
1– 4	1,330	838	61
5– 8	946	300	76
9–14	1,673	620	73

Of the fourteen, ten are on the right, averaging 395 paces long each, and four on the left, averaging 439. Here are scaurs four times as long as those on the Rouge, more frequent on the right than on the left; but the average individual on the right is not quite so long. That the Raisin here is standing well to the right is beyond question. Driftwood shows the plain is well flooded.

This character begins on the southern branch of the Raisin, as has been said, about a quarter way from the elbow at Blissfield to Dundee. Above this point to near Adrian, flood-plain is mostly lacking. Mr Colby notes for this tract, "Nearly all the way the river flows between well defined banks on which the high-water mark shows plainly," and the writer found the same thing east of Blissfield. There is active erosion of the bank at

the outside of each meander; such are all the scaurs there are. Something like 50 per cent of these are on the right, but no significance is attached to that. Apparently the undeveloped valley is due, as at Milan, to the fact that the Warren beach crosses the river along here and gives greater depth of material to be handled.

Paw Paw River

It was regarded as of especial interest to examine some west-flowing streams on the other border of the state. The country has had no detailed mapping, but it appears from the plate referred to in Leverett's monograph that the Paw Paw flowed to the southwest on a plain of gravel, a line of glacial drainage between morainic hills. The stream had limits set to its valley by the moraine, but it seemed as if it should be free to express a preference for a course to right or left by attacking either valley wall. It was known to meander strongly, having been described by students in connection with the outlet stream from Paw Paw lake, which flows out to the river in dry weather, in to the lake in wet, as in the cases described by Burr and Ganong.

The Paw Paw was visited at Watervliet in August, 1906, and about 8 miles of its bank examined, mostly upstream from that place. The bluffs are densely overgrown with thickets and woods, so that the river was not only rarely in scaur, but access to it was very difficult. Of bare scaurs only four were counted, all well toward the first bridge east of Watervliet. They measure—right, 35; left, 48; right, 44, and right, 70. If, however, the strong bluff standing at the water's edge, 45 degrees steep, is counted, two-thirds of it is on the left. This includes in the count 975 paces of bluff on the left, within the village of Watervliet, that is now abandoned course, since the Syms, Dudley Paper Company cut through it in 1895. Then 11 per cent of the bluff is in scaur. Grouping the scaurs or slipping bluffs in fives, we have:

Scaurs.	Paces of slipping bluff on—		Per cent of slipping bluff to left.
	Right.	Left.	
1– 5	475	503	51
6–10	785	2,122	73
11–16	149	279	65
All.....	1,409	2,904	67

The nine scaurs on the left average 323 paces long, the seven on the right 201. The stream is undoubtedly cutting most strongly on the left side. The flood-plain, which is a true one, has been widened about in this way: Deep scallops have been cut for the plain border in the upland on the left (south), then the river cut some sort of scaur on the up-valley side of the reentrant cusps between scallops. The only place at which anything scaur-like occurs on the opposite bank, being invariably at the tip of long meanders that have looped out across the plain from the scallops and touched the northern bank without, however, notching it in any case examined. The log rollways on the south bank are stated by reliable lumbermen to be higher than those on the north all the way to Benton harbor. Of the scallops mentioned as strongly developed on the south side, two or three unusual examples are immediately west of the railway station at Watervliet. No example was seen on the north in the tract studied.

CONCLUSIONS

The lower and middle Rouge, Rattle run, Huron, Saline, Raisin, and Paw Paw show persistent and uniform tendencies toward one or the other side of their valleys wherever there is a flood-plain on which the streams meander between distinct bluffs. The lower and middle Rouge, Rattle run, and Huron, flowing toward points between southeast and east-northeast, bear strongly to the right. The northern Rouge and parts of the Saline and Raisin have channels incised between banks that their flood waters fail to surmount. Here lateral erosion is irregular and lacks definite tendencies. Other points on the Raisin bear hard to the right, the Saline as hard to the left at points where perhaps their behavior is due to restraint by Lake Warren beach ridges parallel to which they flow. The Paw Paw, flowing to the southwest, bears strongly and uniformly to the left.

The left-handed rotation of the earth on its axis should make all moving bodies in the Lake country seem to bear off to the right. If this explains the action of the eastern streams it leaves the Paw Paw beyond the pale of law. If we have interpreted rightly the behavior of Saline and Raisin at Dundee, the others have this in common, that they all bear somewhat to the south. The tilting of the region toward south 27 degrees west, described by Gilbert, might account for such a tendency. Taylor, Lane, and Goldthwait have recently pointed out that the old

beaches south of Port Austin, on the Thumb of Michigan, are not perceptibly out of level. Inference has been made from their results that "no earth movements have affected this region since the earliest Algonkian stage, and that if any deformations are now in progress in these two lake basins, they are limited to the more northerly portions." Gilbert's result, on the other hand, seems to give an entire preponderance of evidence that the region was tipping southward along the line mentioned above, at the rate of about 5 inches per hundred miles per century, *between the years 1858 and 1896*. Gilbert's work rests on three independent pairs of stations on lakes Michigan, Erie, and Ontario, two of which reach across the region of the present study of rivers. Bench-marks regarded as stable at these pairs of stations were compared with the observed height of water in the Great lakes during a considerable period of suitable weather, identical period for the two stations of each pair—in 1876, lake Michigan; 1858, lake Erie, and 1874, lake Ontario. The comparisons were repeated in 1895 and 1896. Doctor Gilbert found the southern station seemed to sink in the interval an amount that, when allowance is made for distance and time elapsed, is equivalent to a depression at the south end of a line running south 27 degrees west of 0.43, 0.46, and 0.37 feet per hundred miles per century—three independent values that strongly confirm each other. Using the southern lake Michigan station over again, paired with Port Austin, in lake Huron, a comparable value of 0.39 foot is obtained; but this of course is not independent of the lake Michigan pair. The accuracy of the result rests on the stability of the bench-marks. Any one of them may have changed. But that all three southern marks shall have changed by amounts that lead to results so accordant and systematic as these is very improbable. The lake Michigan pair lie north and south of our area, the lake Erie pair reach into it. Examination of the evidence cited in Goldthwait with regard to beach levels reveals nothing incompatible with this result. Any individual determination of the elevation of a beach may be several feet in doubt. A beach is a somewhat indefinite object to determine with precision. We note in the descriptions of writers such phrases as "about 20 feet," "10 to 15 feet" above the lake, and so on. That the lake surface is incessantly fluctuating by amounts covering several feet is not explicitly noted by geologists. Perhaps they recognize those fluctuations as less than the uncertainty involved in deciding at just what point they are to measure the elevation of the beach. If this be true, it is possible that a tilting to the amount of two or three feet actual sinking of the

southern part of the region may have occurred without bringing the beaches perceptibly out of level. The tilting that Gilbert finds occurred between 1858 and 1896 may have gone on for the last 700 years (7 times 5 inches equals 35 inches), and yet the beach would not be three feet out of level in a hundred miles today. Can any one, from a study of these beaches, assert that they are not deformed to that amount? Would seven centuries suffice to give the rivers a distinct tendency toward the south? There are no criteria at hand for an answer; but the supposition that they might does not seem unreasonable.

It does not seem to the author that sufficient evidence has been gathered to say that the rivers support the view. The most that he would claim is that their evidence is in accordance with such a view as far as it goes.

From this point of view streams may be classified according to the angle that their course makes with the direction south 27 degrees west. If a tilting in that direction is affecting the flow of streams, it should hasten those flowing south 27 degrees west, causing them to deepen their channels, as has happened to the North branch of the Rouge. Those flowing north 27 degrees east it should check, making their course swampy and abounding in pools, as is believed to have happened to the Concord and upper Charles, in Massachusetts, from this same cause. Those flowing east 27 degrees south or west 27 degrees north should attack their banks to right and left respectively. Intermediate directions should show intermediate effects. Morainal and shoreline guidance is likely to render such criteria at times hard to apply.

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SOME CHARACTERISTICS OF THE GLACIAL PERIOD IN NON-GLACIATED REGIONS*

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CONTENTS

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Introduction

In the progress of geology the influence of climate has been one of the last great subjects to receive attention. During a residence of four years in the dry eastern part of Asiatic Turkey, from 1897 to 1901, the importance of climatic influences was impressed on me by the contrast between the topography and superficial deposits of that semi-arid region and those of the moister, glaciated portion of the United States. The impression was strengthened in 1902, when, as a member of a party under the leadership of Professor Davis, of Harvard University, I visited the arid region of Utah and Arizona. There, not only do the superficial deposits and topography bear the impress of prolonged aridity, but the wonderful cross-bedding of the white Colob sandstone and the red color of the underlying Kanab formation apparently point to the existence of still more arid conditions during the Mesozoic era.

In the spring of 1903, as assistant once more to Professor Davis, I accompanied the Pumpelly expedition of the Carnegie Institution of Washington to Russian Turkestan. Thence I made journeys to Kashgar, in Chinese Turkestan, in the summer of 1903, and to Seyistan (Sistan or Seistan), in eastern Persia, early in 1904. In these countries, as is set forth in "Explorations in Turkestan," still stronger evidences of the geologic importance of climate present themselves. The next year, 1905, brought an opportunity for a journey of fifteen months' duration in northern India, Chinese Turkestan, and Siberia, as a member of Mr Robert L. Barrett's expedition to Central Asia. In Chinese Turkestan I traversed what is probably the most unmitigated desert in the world, the great salt plain of Lop. Since the completion of this last journey, the liberal terms of a Hooper Fellowship, held as a non-resident member of the Graduate School of Arts and Sciences of Harvard University, have

FIGURE 1.—*Sketch Map of Areas investigated.*
Reproduced from "The Pulse of Asia," by permission of Houghton, Mifflin & Company.

permitted me to devote an uninterrupted year to the preparation of a narrative of the journey in Chinese Turkestan, entitled "The Pulse of Asia," and to the study of various climatic problems, some of which are discussed in the following pages.

Relative Importance of Glaciation and of other Evidences of climatic Changes

The investigations outlined above have led to the conclusion that some of the most important criteria for the recognition of change of climate have as yet largely escaped attention, because they occur in almost uninhabited arid regions. In regard to the Pleistocene Glacial period—the standard example of climatic change—the fact that the science of geology has been studied chiefly in North America and Europe has naturally given great prominence to the idea of glaciation, leaving other phases of the subject comparatively unconsidered. It is a well established fact, however, that, not only in glaciated regions, but in other parts of the world as well, the Glacial period was preeminently a time of rapid climatic changes. Everywhere the changes must have produced results of some sort, even where there were no glaciers. It is to a study of these results and of their significance that the present paper is directed.

In North America and Europe, to restate a familiar fact, a tenth or more of the land surface of the globe was covered with ice during the Pleistocene period. A great glacial sheet scoured away the soil and rock, scratched and rounded the hills, broadened the valleys, and deposited hummocky moraines and plains of till. In other parts of the world glaciation was limited to a few comparatively small mountainous areas. There, as in the larger regions, the depth of snow on the ground increased, because the temperature was lower or because the snowy precipitation was greater than before. New glaciers were formed in the higher valleys and old glaciers increased in size; yet at a maximum the area covered by ice probably never exceeded 15 per cent of the land of the globe. Moreover, glaciation was a feature of *glacial* epochs only, not of *interglacial* epochs. Therefore we are warranted in saying that glaciation, though extremely important, was only a local feature of the period to which it has given a name.

Typical Features of a River in an arid Region

1. *GLACIAL FEATURES*

An examination of a typical river in central Asia will illustrate the manner in which the changes of climate of the Pleistocene period have

produced a variety of results in addition to glaciation. Let us take one of the main branches of the great Tarim river, in the arid country of Chinese Turkestan. Its source is among the glaciers of the lofty, snow-clad mountains of Kwen Lun, grander than the Alps. When a period of relatively cold or moist climate prevailed at some past time, the snow-fields increased in size and perhaps in depth; the glaciers grew larger; they gnawed back their cirques and steepened the walls of their valleys; they deepened and smoothed the bottoms also, and the main glaciers cut so much more powerfully than the tributaries that the valleys of the latter were left hanging upon the sides of the main U-shaped trough; and finally the glaciers deposited huge moraines at the point of final melting. From the moraines gravel and detritus were washed forward, filling the bottom of the valley for a space. When a change to warmer or drier conditions ensued, the ice withdrew, the load supplied by it to the stream diminished, the river began to erode the moraines and the deposits near them, and terraces were formed. All these features are distinctly glacial. In the small area of their occurrence at the head of the river, the alternating climatic epochs of the Pleistocene may well be called "glacial" and "interglacial."

2. *FLUVIAL FEATURES*

Downstream from the glacial region the valley ceases to be U-shaped. It becomes narrow and V-shaped, and the terraces die out. When the valley broadens again among the lower mountains, where the strata are softer and erosion along the present lines has proceeded farther, terraces once more appear. No connection, however, can be detected with those farther upstream or with glaciers. It appears, as will be shown later, that they are due to the effect which changes of climate produce on rivers, just as the features higher up are due to the effect which changes of climate produce on glaciers. On leaving the mountains the Tarim river enters the great plain which forms the floor of the Lop, or Tarim basin. Terraces disappear, but there is other evidence that during glacial epochs conditions were different from those of interglacial epochs. There is no direct proof that the main river was larger than now, although there can be little doubt that such was the case. The tributaries were quite surely larger; for at the lower ends of many small streams which now wither to nothing in the piedmont gravel or sand of the basin floor, there are old channels and strips of dead vegetation showing that at a comparatively recent time the streams flowed farther than they now do. Throughout its whole length from the end of the glacial portion to the mouth, changes of climate appear to have had a marked effect on the activity of the

Tarim river. The same is true of countless other rivers, especially in arid regions. It is probable that changes in rivers have been much more widespread than changes in glaciers. Hence the term "fluvial" is quite as appropriate as the term "glacial." It has been much less used simply because the behavior of rivers under the influence of climatic changes has been studied much less than has that of glaciers.

3. *LACUSTRAL FEATURES*

At the lower end of the Tarim river the lake of Lop-Nor furnishes an example of still another kind of result produced by changes of climate. Today the lake is a shallow reedy swamp. Old shorelines at various elevations up to 600 feet (see plate 31, p. 368) indicate that during the Glacial period its size was enormously greater than now, although during interglacial epochs there is reason to believe that it contracted to small proportions. Other examples of lakes which expanded during the Glacial period might easily be cited. Moreover, in America and Europe a great number of new lakes of a different type, such as those of Minnesota or Switzerland, were formed at that time. Glacial lakes are almost coextensive with glacial deposits, and are one of the most striking results of climatic changes; therefore "lacustral" is a term of the same order of importance as "glacial" and "fluvial" and might equally well be used as a general term.

Types and Results of Changes of Climate as distinguished from the Agents producing the Results

The terms glacial, fluvial, and lacustral are derived from three inorganic *agents* whose behavior changes markedly under the influence of changes of climate. In place of these another set of terms is often used, denoting the *type* of change which gives rise to the varied behavior of the inorganic agents. The most common of these are moist and dry, cold and warm, pluvial and arid. For general use they are no better than the terms based on the agents. They are equally local and partial, and they assume a knowledge which we do not possess. We do not yet know whether the Pleistocene changes of climate were due to variations in precipitation, in temperature, or in both. There is good reason to believe that the changes produced an oscillation between *moister* and *drier* conditions, for this would be the case whether the rainfall or the temperature varied; increased rainfall would mean an absolutely greater amount of water, and lower temperature would diminish the rate of evaporation so that the available supply of water would be increased. The changes in different parts of the earth, however, must have been of very diverse na-

ture. In one place the climate may have varied from very cold to cold, while in another at the same time it ranged from warm to hot; or, again, the change may have been from wet to dry in one place, and from dry to very dry in another.

A complete view of a period of climatic changes involves a study not only of the types of change and of their influence on active agents, such as glaciers, rivers, and lakes, but also of the results produced on land forms and on life. The results of glacial action in the form of moraines, till plains, cirques, and so forth, are well known. So, too, are the results of the action of lakes which give rise to strands marked by beaches and bluffs, and to deposits varying according to the conditions of deposition. The results of the action of rivers under the influence of changes of climate have received less attention, although it appears probable that they can be detected in a large part of the arid and semi-arid regions of the earth. They take the form of terraces, and of subaerial deposits, the texture and structure of which vary in response to the climatic conditions under which they are laid down. On the deposits I shall not here dwell, because their investigation has not as yet proceeded far. The reasons for believing that many terraces are due to changes of climate have been set forth in "Explorations in Turkestan" and elsewhere, but may here be briefly reviewed.

Climatic Theory of fluvial Terraces

Throughout western and central Asia a large proportion of the valleys among mountains of fairly mature topography and of arid or semi-arid climate contains terraces. Where best developed, the terraces number five, not counting an incipient sixth. The oldest and outermost are of large size, often several hundred feet in height. They are composed of gravel and silt, often more or less consolidated. Except where accidentally renewed by the modern undercutting of streams, they are characterized by gentle slopes and much battering and erosion, showing that they are comparatively old. The other terraces are successively younger; they are composed of less consolidated material, but, nevertheless, are not so much worn. Over vast areas the number, the relative size, the relative amount of weathering and erosion, and the structure and form of the terraces are the same. This is true not only in valleys lying close to one another, but in those of remote regions one or two thousand miles apart. It appears impossible to explain the terraces as due to warping of the earth's crust, because of their uniformity over wide areas and because they occur in valleys which interlock in such a way that a movement which caused ter-

racing in one could not cause it in the other. The terraces are clearly not due directly or indirectly to glacial action, for they occur indifferently in valleys which have or have had glaciers at their heads and in those in which there is not the slightest trace of glaciation, along either the main river or any of the tributaries. There appears, however, to be a relation between glaciers and terraces, for the number and relative size of the old moraines of central Asia is the same as that of the terraces. Moreover, in certain cases terraces are so related to moraines that, although there is no evidence that ice-action caused the terraces, it yet appears that the terraces and the moraines were in process of formation at the same time.

Again, in number, relative size, and age, the terraces appear to be identical with the old lacustrine strands, although here again there is no evidence that the lakes had anything to do with the terraces.

In view of all the facts, it seems probable that the terraces bear the same relation to the rivers that the moraines do to the glaciers and the strands to the lakes; that is, all three land forms appear to be due to the varying way in which water, under the influence of climatic changes, has acted in its course from the mountains, where it assumed the form of ice and snow, through the length of the rivers, to the lakes.

The process of climatic terrace-making appears to be as follows: In arid regions during a moist epoch—whether the moisture be due to heavier precipitation or to diminished evaporation because of lower temperature—the processes of weathering are more active and soil is formed faster than in a dry epoch. Moreover, the moisture causes vegetation to flourish to a degree impossible under drier conditions. The vegetation holds the new-formed soil in place, even though the rainfall increase and the rivers and rivulets become more capable of erosion than formerly. If the moist epoch last long, the mountains of arid countries, such as Persia, for example, must lose their naked character and become well shrouded with rock waste. On the advent of a dry epoch two marked changes occur: part of the vegetation disappears; and the contrast between dry seasons and wet seasons is more marked than formerly, although the proportion of rainfall in each may be the same as before. The soil on the mountains is no longer protected by roots and leaves, and is exposed at intervals to violent erosion, because the rain runs off quickly, now that the protecting cover of plants is removed. The rock-waste mantling the slopes is washed down into the valleys, and accumulates there because the heavily loaded streams can not carry it all away. In course of time the slopes are stripped of loose material, or else the climate again becomes moist and vegetation becomes abundant. In either case the load of the streams is less heavy than formerly, and the rivers begin to dissect the

deposits on the top of which they have hitherto been flowing. Thus, apparently, a terrace is formed; and a repetition of the process gives rise to a series, provided neither deposition nor erosion proceeds so far as to efface the earlier terraces. In western and central Asia, throughout an area at least 3,000 miles long from east to west and 1,500 miles wide from north to south, one everywhere finds terraces which appear to be of climatic origin. Similar terraces are also found in Arizona and Utah, although these have not been critically investigated and usually have been considered to be due to earth-movements.

Influence of Changes of Climate on Vegetation—Loess

Perhaps the most important of all the results of changes of climate is the effect on life. Reference has already been made to large areas of dead vegetation, which are located at the ends of withering rivers and which form a notable feature of the deserts of the Lop basin. The inferred influence of the growth of plants on the accumulation of soil and on the formation of terraces has also been mentioned. An effect kindred to this last is seen in many places on the south side of the Lop basin. The prevailing winds of this region are from northerly quarters across the great sandy desert of Takla-Makan. The moving air picks up vast quantities of fine dust, which, during the summer, fills the air with a dense haze for weeks at a time. Fine yellow dust is constantly falling at such a rate that a visible layer accumulates in a day in a pan of water set in the middle of a field of grass. Time and again I tried this experiment with the same result, even though the region within ten or twenty miles had been moistened by a shower within a few hours. The great desert to the north had not been moistened, and its loose, dry dust was continually being carried into the upper air, not only by ordinary winds, but by great dust-whirls a thousand or more feet high. From a mountain-top I several times watched a cloud of dust approach from the desert after a storm. It filled the air to a height of thousands of feet, and advanced steadily before a gentle breeze scarcely perceptible to the observer. In this way the northern slope of the Kwen Lun mountains south of the Lop basin is being showered with yellow dust, which is nothing more nor less than loess of the most typical sort. Wherever there is sufficient vegetation, which is only close to the higher mountains—where the rainfall is comparatively large—the dust is held in place, and heavy deposits of loess are in process of accumulation. Lower down the mountains, where the rainfall and vegetation are less abundant, there is also much loess, but it is being dissected and carried away. Apparently it was deposited at some former time, when conditions were different from those of today. The difference

was quite surely in the amount of vegetation. Formerly, during glacial times, there was apparently more; now there is less. It seems safe to infer that this process of the growth and the dying off of vegetation has gone on again and again as glacial epochs have given place to interglacial. Similar effects are known to have taken place in other regions. Animals as well as plants have been influenced, and so, too, has man, as I have shown in "The Pulse of Asia;" but the most fundamental organic change has been the response of vegetation to varying types of climate. It has probably taken place in almost all parts of the continents. In view of this, it seems as if we were warranted in speaking of "vegetal" epochs with the same freedom with which we speak of "glacial" and "fluvial" epochs. The term is not, however, sufficiently general. Like glacial and all the others, it is somewhat local in its significance, and it applies to only one of the many phases characteristic of epochs of climatic change. Its use, like that of "glacial," or any other of the terms to which reference has been made, is misleading, because it unavoidably carries with it the implication that it expresses the most important feature of the epochs which it characterizes. Each of the terms is useful, but something is needed which shall embrace them all.

Résumé of Characteristics of the Pleistocene Period of climatic Changes

The characteristics of the Pleistocene period of climatic changes have been grouped above into four categories:

First in logical order, though not the most noticeable, are those pertaining to the nature or type of the changes. They are described by such words as moist and dry, cold and warm, pluvial and arid.

The next group of characteristics consists of those pertaining to the active agents which are directly affected by climatic oscillations, and which in turn work upon other things and produce tangible results, although the agents themselves pass away. They are described by the terms glacial, meaning that glaciers are important, and interglacial, meaning that glaciers are unimportant, and by the terms fluvial and interfluvial, and lacustral and interlacustral, having similar significance as to rivers and lakes. It might be well to have another pair of terms indicating the importance or lack of importance of underground water, but this perhaps may be included in fluvial, which may be taken to apply to all flowing water, whether above ground or below.

A third group of characteristics consists of those pertaining to the visible products of the work of the agents of the last group. For those we have no good adjectives. They may be described as concerned with moraines or intermorainic deposits, with the formation and the stripping of

a mantle of soil in arid regions, with the deposition or the erosion of the materials of terraces, and with the formation of lacustrine strands and deposits, and the results produced when lakes retreat from a high stand.

Finally, we have a group of characteristics of epochs of climatic change dependent upon the influence exerted upon life. As animal life depends almost entirely on vegetable life, it is enough to speak of vegetal and intervegetal conditions.

RHYTHMIC NATURE OF CLIMATIC CHANGES—SUGGESTION OF NEW TERMS DERIVED FROM THE RHYTHM OF POETRY

In the preceding summary of the characteristics of the Pleistocene period of climatic changes it is noticeable that all the descriptive terms are in pairs. Diverse as they are in many respects, they all possess this unity. The great, outstanding characteristic of climatic changes, as we know them, is their rhythmic quality. This is universal, pertaining to each and all of the activities or results engendered by the swing of climate from one extreme to the other. A series of climatic changes such as that of the Pleistocene is like a line of poetry, or a stanza, in which there is a constant repetition of a certain definite series of accented and unaccented measures. In order to have terms which shall be applicable to all parts of the world, and which shall not run the risk of being misinterpreted because they carry only a local significance, it seems appropriate to adopt into geology three terms used by the Greeks and Romans to describe the parts of a poetic composition. The words are "strophe," "arsis," and "thesis." They have passed from Latin into English, and are thus defined by the Standard Dictionary:

"*Strophe* (stro′-fi). A metrical form of ancient lyric poetry in which the rhythmical movements are combined into groups that are repeated one or more times. . . . Strophe means literally 'a turning.' At the end of the strophe we turn and repeat the same conditions. . . . Stanza, under another symbol, means the same thing."

"*Arsis* (in prosody). The syllable that receives the ictus or stress of voice, as opposed to the thesis; also the stress itself."

"*Thesis*. In modern prosody . . . the unaccented part of a foot; also, the depression of voice in pronouncing the thesis."

A poetic example will make the matter clear:

Still síts the schóol-house bý the róad,
A rágged béggar súnning.
Aróund it stíll the súmachs grów,
And bláckberry vínes are rúnning.

Within, the master's desk is seen,
Deep scarred by raps official,
The warping floor, the battered seats,
The jack-knife's carved initial.

We have here two strophes, or stanzas. Each consists of regularly recurring arses and theses, or accented and unaccented syllables. The metrical composition of the stanzas presents a close analogy to the course of climate during geological time, as is illustrated in figure 2. In the figure horizontal distance represents the course of time. An upward curve indicates increasing moisture, diminishing temperature, or other conditions pertaining to the phase of a climatic cycle known as glacial, fluvial, lacustral, and so forth. The climax is the *arsis*, and the time in which it occurs is an *arsial* epoch. The appropriateness of the term is evident when one considers the stress which is commonly, and perhaps

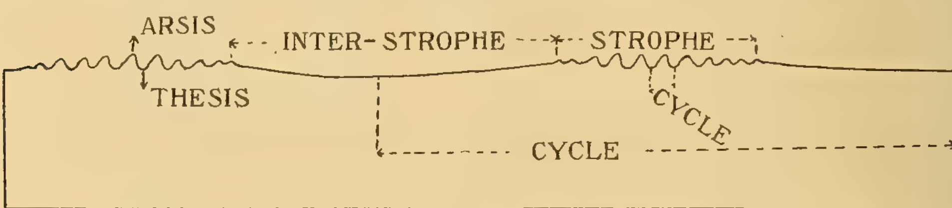

FIGURE 2.—*Diagram illustrating Progress of Changes of Climate during geological Time.*

justly, laid upon the marked features of glacial or fluvial epochs as compared with the less noticeable features of interglacial epochs. A downward curve in the figure represents a tendency toward aridity or warmth, culminating at what may be termed the *thesis*. The time when a thesis occurs is a *thesial* epoch, which may be described as interglacial, or interfluvial, and so forth, when the agents which modify the earth's surface are considered, or as intervegetal, interpluvial, and so forth, when other phases are considered. A group of climatic cycles consisting of alternating accented or arsial epochs and unaccented or thesial epochs forms a *strophe,* just as in poetry a succession of feet composed of arses and theses forms a stanza. Thus we may speak of the Pleistocene strophe of climatic change or the Permian strophe. An intervening period, when changes of climate are less marked or less frequent than during the strophes, would naturally be termed an *interstrophe.*

Importance of climatic Records in arid Basins

Records of climatic change are found chiefly in regions where extremes of one sort or another have prevailed. In a country where arsial

conditions have never been more severe than those of Canada today, and where thesial conditions have been like those of Texas, it is in vain to look for any very marked evidences of a climatic strophe. Under more extreme conditions, however, a much slighter change will produce far more manifest and permanent results. For instance, a change from the climate of northern Canada to that of Greenland would cause glaciation, and a change from the climate of Utah to that of Montana would cause the expansion of inclosed lakes. Hence, in studying the Pleistocene strophe, attention has been devoted mainly to glaciated countries, on the one hand, and to arid regions, where the lakes have no outlets, on the other. Glacial deposits, including till-sheets and moraines, are commonly laid down in regions of more or less relief, where erosion is comparatively active. Therefore they are liable to relatively rapid destruction. Moreover, the deposits of one arsial epoch are in imminent danger of being destroyed in the next. In arid basins the case is very different. Erosion is at a minimum or absent, and the deposits of one epoch are usually laid immediately on those of its predecessor. Everything combines to preserve a complete record of all the changes, climatic and otherwise, to which the given region has been subjected. Generally the record is inaccessible. If, however, by uplift or otherwise, it is exposed and dissected, it furnishes a most valuable means of supplementing the glacial record by filling in the gaps, and by indicating the occurrence of early events whose record in colder lands has been completely effaced by successive incursions of ice.

The Basin of Seyistan, in eastern Persia

GENERAL DESCRIPTION OF THE BASIN

In the arid basins of Seyistan, in eastern Persia, and of Lop and Turfan, in Chinese Turkestan, such records of the Pleistocene strophe are found. The evidence of all three basins appears to agree in indicating that the strophe was very complex, and that there were several cycles of climatic change preceding those of which the record is preserved in glaciated regions. The basin of Seyistan, which I have described in "Explorations in Turkestan," comprises a mountain-girt area of about 200,000 square miles in southwestern Afghanistan, northwestern Baluchistan, and eastern Persia. The climate is so dry that many of the streams wither away and are lost in the vast piedmont slopes of gravel at the base of the encircling mountains. The rest unite to form the Helmund river, which flows toward the corner where Persia joins Afghanistan and Baluchistan. There the river gives rise to two lakes lying at almost the same level. One, called the Hamun-i-Seyistan

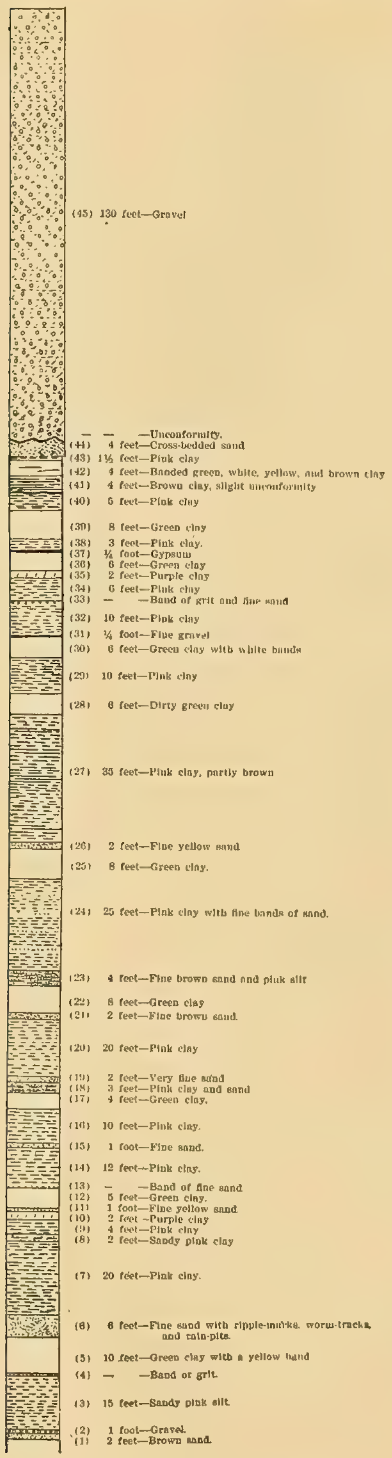

FIGURE 3.—*Section of Clay Deposits in old Lake Bed of Seyistan.*

Locality near Kuh-i-chaku, northwest of the lake. Scale: 1 inch = 60 feet.

(swamp of Seyistan), is a broad and exceedingly shallow expanse of fresh water surrounded by a vast reedy swamp. Occasionally, during years of unusually high floods, this lake discharges to another lying farther south, the intensely salt God-i-Zirrah. Both lakes are surrounded by the bed of an older, larger lake. The bed is a plain, splendidly fertile wherever water is available for irrigation. It is surrounded by a bluff cut by the expanded lake of ancient times. At the top of the bluff a huge desert of wind-blown sand and parched gravel stretches mile after mile toward the distant mountains.

During the latter part of the Quaternary era volcanoes broke out in various places within the limits of the old lake. In the course of their eruptions earth movements took place, and large portions of the lake bottom were uplifted and covered in part with caps of lava. Subsequent erosion by the lake has cut into the uplifted strata, with the result that in some places there are bluffs from 400 to 600 feet high. The strata thus exposed reveal the history of the Seyistan basin during and preceding the time known elsewhere as the Glacial period. The record is simple and apparently easy to interpret. There is no greater emphasis on one phase than on another, and nothing seems to be lost.

PLEISTOCENE (AND PLIOCENE) DEPOSITS OF SEYISTAN

1. *Subaerial red beds.* — The nature of the deposits uplifted at the

time of the Seyistan volcanoes and exposed in the lacustrine bluffs is shown in the accompanying sections (figures 3 and 4). The main body of the deposits consists of numerous alternations between thick reddish or pinkish strata and thinner strata of a white or greenish color. The pink beds consist largely of clays and very fine silts, which often pass into fine brown sand. Viewed as a whole, the pink layers are very continuous and preserve the same character for mile after mile. In detail, however, they vary considerably, even in short distances. For instance, a layer of clay is often interrupted by a band of fine sand which continues a few hundred feet and then dies out. More rarely a layer of grit or fine gravel is exposed, and, rarest of all, a distinct fossil stream bed. Again, in certain places slight unconformities are discernible, as if a little erosion had taken place between the deposition of one layer and the next. Among the more sandy layers there are further evidences of exposure to the air. In one place, for intance, the sand shows ripple-marks, worm-casts, and raindrop prints. Finally, the layers of this formation are everywhere of a reddish tint, varying from pink to brown. The only exception is found in some of the sandier, more quartzose layers, which are gray for a few inches. Everywhere the materials appear to have been exposed to oxidization for a considerable period under subaerial conditions of such aridity that few or no plants were present. Thus, on the one hand there was nothing such as a superincumbent sheet of water to prevent decomposition and oxidization, and on the other there was no vegetation to leach out the oxidized iron and prevent the deposits from assuming a red color. Apparently the pink beds were deposited sub-

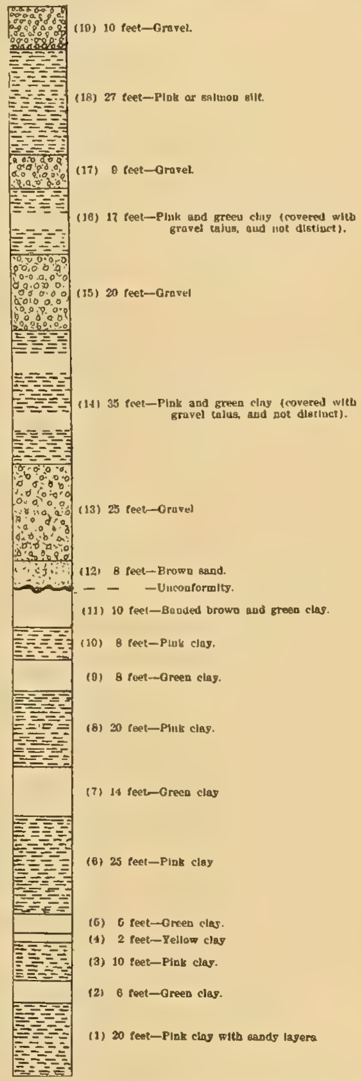

FIGURE 4.—*Section of Clay Deposits in old Lake Bed of Seyistan.*

Locality near that of figure 3. Scale: 1 inch = 60 feet.

aerially by occasional widely spreading floods, or in temporary playas, during periods of extreme aridity.

2. *White or light-colored lacustrine clays.*—The white or, more exactly, the greenish clays, are very different from the red layers with which they are interbedded. On the upper and lower edges they are mixed with fine sand or are more or less banded. Occasionally a purple layer occurs or a band of yellow clay and fine sand in which are fossil leaves and reeds. The main mass of each stratum, however, consists of solid, unbroken layers of pure clay, uniform in texture and color and showing none of the slight variations characteristic of the pink beds. The color indicates that the materials were brought quickly from their place of origin among the mountains and have never been long exposed to erosion, or else that whatever oxidization has taken place occurred in the presence of plants capable of removing the oxidized iron. Whichever may be the case, the green strata as a whole show no sign of subaerial origin and appear to be typically lacustrine.

CLIMATIC SIGNIFICANCE OF THE ALTERNATING RED AND WHITE STRATA OF SEYISTAN

The red or pink and the white or green beds differ from one another chiefly in the conditions of deposition. The material of the clayey portions of the pink appears to be identical with that of the green, except that it contains a large amount of oxidized iron. It is reasonably certain that both pink and green were derived from the same source. The alternation of such subaerial and subaqueous beds indicates that during the most recent geological times the lake of Seyistan has alternately retreated from and encroached upon large areas of its quondam bed. The duration of each epoch of retreat and encroachment must have been considerable, for the accumulation of from 5 to 20 feet of the finest clay must have taken some thousands of years, if deposition was formerly as slow as it now appears to be in the Hamun-i-Seyistan at a distance from the river mouths. The change from subaerial to lacustrine conditions and the reverse must have been gradual, for the pink and green deposits often shade into one another. The sandy layers mixed with the upper and lower portions of the lacustrine clay seem to indicate shore conditions, and the layers of yellow or purple clay with the inclosed fossil plants point to the existence of marshes, like the swamps of today, on the shores of the retreating or advancing lake.

When we attempt to explain the variations in the lake, four hypotheses present themselves: First, the lake may have had an outlet which was repeatedly dammed by volcanic eruptions or otherwise, and as frequently

swept clear; second, a large tributary may have been alternately diverted to and from the lake; third, the region of Seyistan may have been subjected to a highly specialized type of rhythmic earth-movements whereby the lake was poured from side to side or its bottom was repeatedly raised and lowered; and, fourth, the Pleistocene strophic period may have consisted of a much larger number of epochs than has been commonly supposed from a study of glaciation. Only the fourth hypothesis appears tenable, as I have shown in "Explorations in Turkestan." A succession of ten arsial epochs of lake expansion alternating with ten thesial epochs of lake contraction would account for all the observed facts of Seyistan.

INDICATIONS OF LATER CHANGES OF CLIMATE AT SEYISTAN

The history of the climate of Seyistan after the time when the clays of the old lake floor were uplifted seems to be continued in three thick deposits of gravel alternating with fine silt. These cap the clays in many places, as appears in figure 4. The gravels and silts seem to be related in the same way as the alternating clays which underlie them, the gravels corresponding to the pink clays, and the silts to the green. The gravel and silt are coarser and more largely subaerial than the clays, apparently because the earth-movements already mentioned uplifted this northwestern part of Seyistan and steepened the grade of the streams.

To the three arsial epochs indicated by the gravels and the ten indicated by the clays we must add two more to account for two strands about 15 and 25 feet above the present average high-water mark. In order to explain all the phenomena of the lake of Seyistan, we are therefore obliged to postulate 15 cycles, each with its arsis and thesis. We rebel at the thought of adding cycle to cycle in this wholesale fashion; yet fifteen or a hundred cycles are as reasonable as one or two. Putting together all the evidence of clays, gravels, and strands, it appears that in eastern Persia the last part of the Tertiary era and the whole of the Quaternary form a strophe characterized by an extraordinary series of climatic oscillations. At first the extremes appear to have been mild or brief, then more severe or longer, and now again mild. The epochs succeeding the maximum appear to correspond to those known elsewhere as characteristic of the Glacial period. Although the correlation has not yet been perfectly established, the lacustrine strands and the gravel deposits of Seyistan appear to be synchronous with the series of fluvial terraces found universally in Persia and Turkestan. The terraces, as has been said, can be correlated with the moraines of central Asia, and there is no reasonable doubt that the moraines are synchronous with those of Europe.

Lop-Nor and the Basin of Lop, in Chinese Turkestan

GENERAL DESCRIPTION OF THE BASIN

Turning now from Seyistan, we find that remoter regions present similar phenomena. Between 1,600 and 1,700 miles east-northeast of Seyistan, as far as from New York to Denver, the almost unknown lake of Lop-Nor lies in the heart of Asia, in the deserts of Chinese Turkestan. Its altitude is about 2,600 feet above the sea, or 1,000 feet higher than Seyistan. During the winter of 1905-1906 I traveled almost completely around the lake, crossing the unexplored eastern end of the vast salt plain of its old bed (plate 32). The lake and basin of Lop belong to the same type as those of Seyistan. A lofty ring of snowy mountains and plateaus encircles a vast desert area of sand and salt extending more than 1,000 miles east and west and 400 north and south. Most of the centripetal streams wither away and disappear in monotonous slopes of piedmont gravel or in the sandy plain of the basin floor. A few of the larger, however, from the north and west, unite to form the Tarim river, which, as we have seen, terminates in the lake of Lop-Nor, 200 miles east of the middle of the basin. Lop-Nor, which can scarcely claim to be a lake, has an area variously estimated at from 60 by 13 to 75 by 18 miles, and consists of beds of vigorous reeds growing in shallow water. At the southwest end, near the mouth of the Tarim river, the water of Lop-Nor is comparatively fresh, but farther east it is intensely salt, and there the reeds come to an end.

ABANDONED LACUSTRINE STRANDS OF LOP-NOR

On all sides save near the river, the swamp is surrounded by the salt plain shown in plates 32 and 33. It has a length of nearly 250 miles and a width of over 60. The plain is bounded by an old strand (plate 31, figure 2) about 12 feet above the present level of the marsh (1906). Above this there are five other unmistakable strands at heights of 20, 35, 115, 300, and 600 feet, as determined by aneroid (plates 31-33). The figures are only approximate. The lowest strand is at least 2 or 3 miles from the lake and often 10 or 20. As I had no means of leveling, it was impossible to ascertain the levels exactly. The two oldest strands lie far back from the lake, and, as appears in plate 31, figure 1, are much covered with talus. Nevertheless they can be clearly distinguished where they lie at the base of high and much dissected bluffs cut by the lake in huge fans of gravel, as at Jilluck, between Vash Sheri and Charklik, and along the northern slope of the little range of Takia Tagh, 150 miles farther east. At its maximum extent the lake was probably about 600

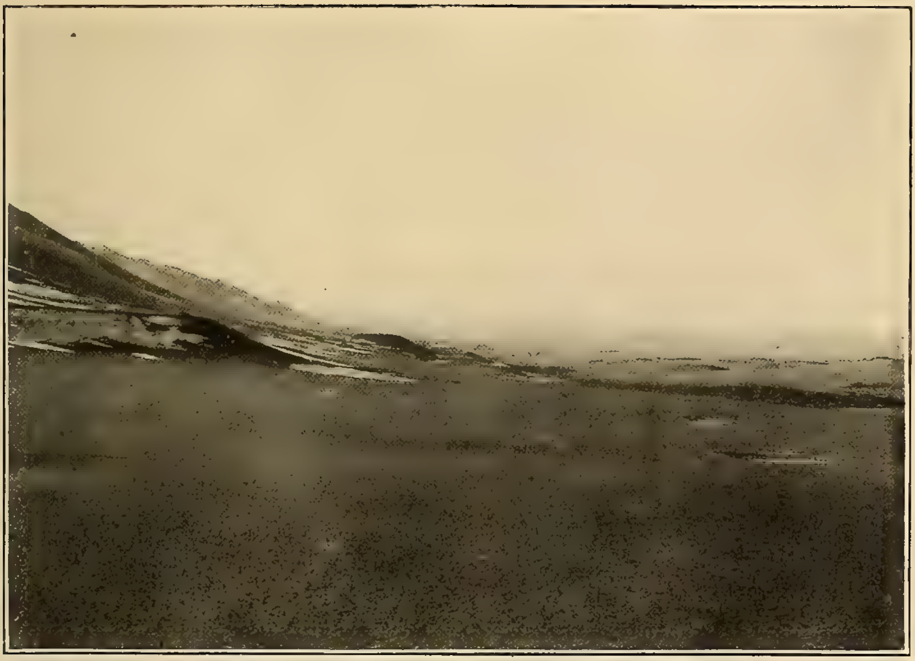

FIGURE 1.—THE 600-FOOT STRAND

Remnants of the 600-foot strand of Lop-Nor cut in piedmont gravel deposits on the north side of Takia Tagh mountains, south of the old lake bed. Looking west

FIGURE 2.—THE LOWER STRANDS

The lower strands of Lop-Nor in Takia bay, near Chindelik salt spring. The man is standing on the 20-foot strand, and the picture is taken at the level of the 35-foot strand. Looking east

STRANDS OF LOP-NOR

FIGURE 1.—THE CENTER OF THE SALT PLAIN

The irregularities consist of solid rock-salt which has broken into pentagons, 8 to 12 feet in diameter, and has buckled up much in the same fashion as mud which cracks in the sun

FIGURE 2.—THE EDGE OF THE SALT PLAIN

The salt of the old lake-bed of Lop-Nor at the foot of the 20-foot bluffs, on the north side of the lake

SALINE SALT PLAIN OF OLD LOP-NOR

FIGURE 1.—THE SOUTH SHORE OF OLD LOP-NOR

The bluffs above the 20 and 35-foot strands south of the salt plain of old Lop-Nor, near Chindelik. At the foot of the bluffs there is a narrow strip of reeds, in which white patches appear. These are pools of brine so saline that they were unfrozen January 1, 1906, after nearly a month of zero weather

FIGURE 2.—ÆOLIAN MESAS NORTH OF LOP-NOR

The mesas are composed of alternating red and white clay. Huge ripples of coarse sand lie in the foreground

BLUFFS AND MESAS OF LOP-NOR

miles long by 125 wide. The three middle strands, at heights of 20, 35, and 115 feet, are usually well developed on both sides of the lake (plate 31, figure 2, and plate 32, figure 1). The youngest is very faint and recent. As has been said above, the strands agree with the terraces and moraines of other parts of central Asia in size and number, and all three kinds of phenomena appear to be synchronous. The small sixth strand, together with a little sixth terrace and a small modern moraine from which the ice has recently withdrawn, appears to be due to a mild arsial epoch dating from historic times.

PLEISTOCENE (AND PLIOCENE) DEPOSITS OF LOP-NOR

At Lop, as at Seyistan, the Pleistocene strophe appears to have been characterized by a series of climatic oscillations, part of which preceded those which can be correlated with the Glacial period. On both the north and south sides of the salt plain I found clayey deposits of lacustrine origin alternating with more sandy subaerial beds. Hedin describes similar strata at the eastern end of the old lake bed, and I found them far to the southwest near Vash Sheri. They appear to cover an area at least 300 miles long and 100 wide. They have been found to a height of over 250 feet above the present lake. The accompanying sections (figures 5-10), all of which are drawn on the scale of 40 feet to the inch, illustrate the character of the deposits. Figure 10 shows the most valuable section. It gives the succession of strata as seen along the dry stream bed running south from Altmish Bulak, a desert salt spring, to the ruins of Lulan, on the north side of the salt plain. It is incomplete at the top and probably at the bottom, and there is a break in the middle. Moreover, it may fail to tell the whole story because the lacustrine strata such as *A* and *B*, figure 11, may not reach the surface. Others, such as *E*, may be very

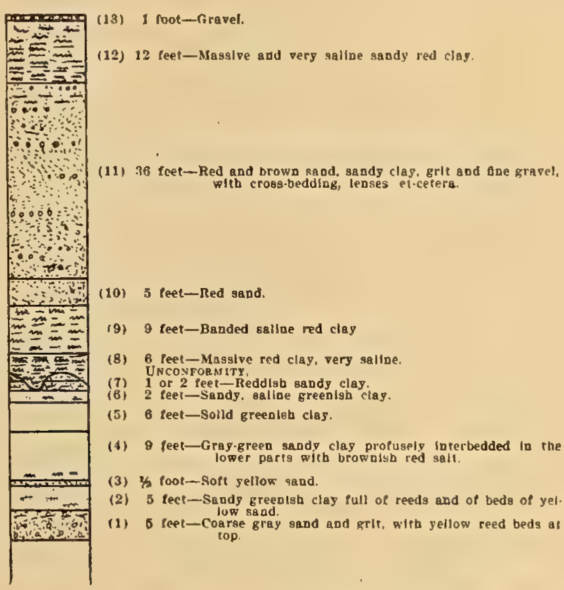

FIGURE 5.—*Section of Lake Bluff 3 Miles East of Chindelik Spring.*

The spring is on shore of old Lop-Nor. Scale: 1 inch = 40 feet.

thin where cut by the bed of the stream, although of considerable thickness farther toward the center of the basin. In many ways the sections at Lop are much less satisfactory than those at Seyistan. Nevertheless they indicate conclusively that in the main the history of the two regions during recent geological times has been identical.

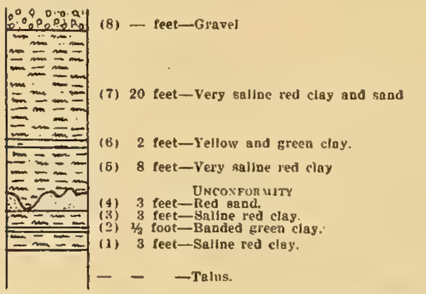

Figure 6.—*Section of Bluff at Takia Bay.*

South of old Lop-Nor. Scale: 1 inch = 40 feet.

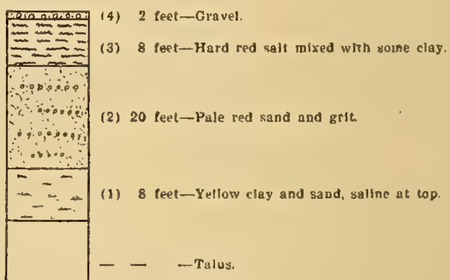

Figure 7.—*Section of Bluff 2 Miles West of Koshalangza.*

Near the east end of old Lop-Nor, on the south side. Scale: 1 inch = 40 feet.

A careful examination of the Lop sections brings out the resemblance to Seyistan. First, we have somewhat massive lacustrine deposits of pure, light-colored clay, varying in tint from almost white to pale green, or, on the edges, pinkish yellow; second, there are numerous sandy yellow reed beds, indicative of swamps, such as now occur in central Asia on the shores of lakes or in the flood-plains of rivers; and, third, we have deposits of gravel or red clay, pointing apparently to arid epochs of lake contraction. Reed beds appear to play a much more important part at Lop than at Seyistan. This is largely because at Lop most of the sections are from near the borders of the old lakes, whereas at Seyistan they are from more central parts. Another difference is the much greater amount of salt at Lop, both in the lacustrine and subaerial deposits. This corresponds with present conditions. The vicinity of Lop-Nor is one of the most saline places in the world. The river Tarim, though drinkable, is so full of salt that it can not be

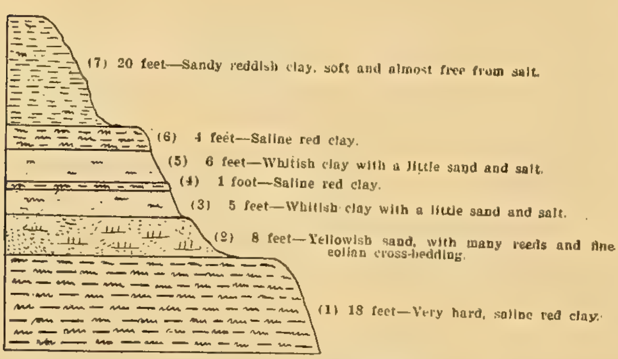

Figure 8.—*Section of a 3-story "Yardang," or Æolian Mesa.*

The mesa is about 25 miles east by south of Altmish Bulak, north of old Lop-Nor. Scale: 1 inch = 40 feet.

Figure 1.—North of the old Lake-bed

An æolian mesa, showing the unconformity of Figure 13

Figure 2.—South of the old Lake-bed

Side of a gully near Chindelik, showing the unconformity of Figures 5, 6, and 12

UNCONFORMITIES AT LOP-NOR

used for irrigation, and most of the few springs in the region are so saline as to be absolutely undrinkable in summer. Even in winter, when it is possible to cut out the best part of the ice around the springs and melt it for drinking water, my men and I found that after a drink we were usually more thirsty than before, although our thirst passed away within an hour or two. It is noticeable that the most highly saline parts of the deposits at Lop are usually red. Their appearance suggests that they were deposited by the drying up of successive sheets of water. The color seems to indicate exposure to the air before each layer was covered by its successor. Probably the salt was deposited in great playas, which disappeared during dry seasons. At present Lop-Nor varies greatly in size from year to year and is surrounded by dirty brownish white deposits of salt.

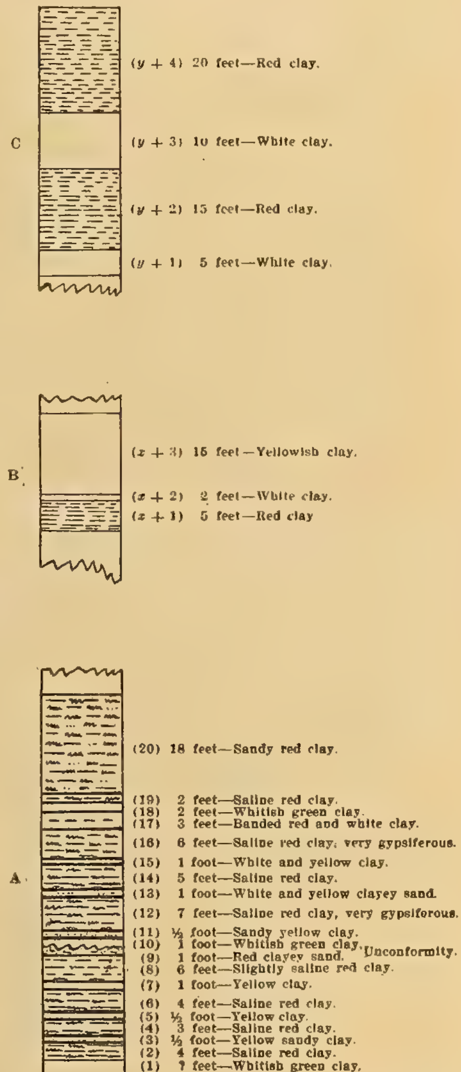

FIGURE 9.—*Section near Locality referred to in Figure 8.*

B and C are two sections supplementary to A. They lie above it, but the exact relationship is not known. Scale: 1 inch = 40 feet.

UNCONFORMITIES AND BURIED STRANDS OF LOP

The unconformities in the Lop-Nor deposits are almost as important as the strata themselves (see plate 34). Those of figures 12 and 13 lie at about the same elevation on opposite sides of the lake. As they are 80 miles apart, it is impossible to be sure as to their relation. They appear, however, to be of the same age. The strata lying above the main unconformity, *A-B*, in each case, seem to correspond to those lying above the break in figure 10. The unconformity shown in figure 12 is the same as that of figure 5, which is not far distant. In figure 12 a great amount of erosion has taken place because of the presence of a large stream at the time when the unconformity was formed. The gravels numbered 5 in the section were deposited by the

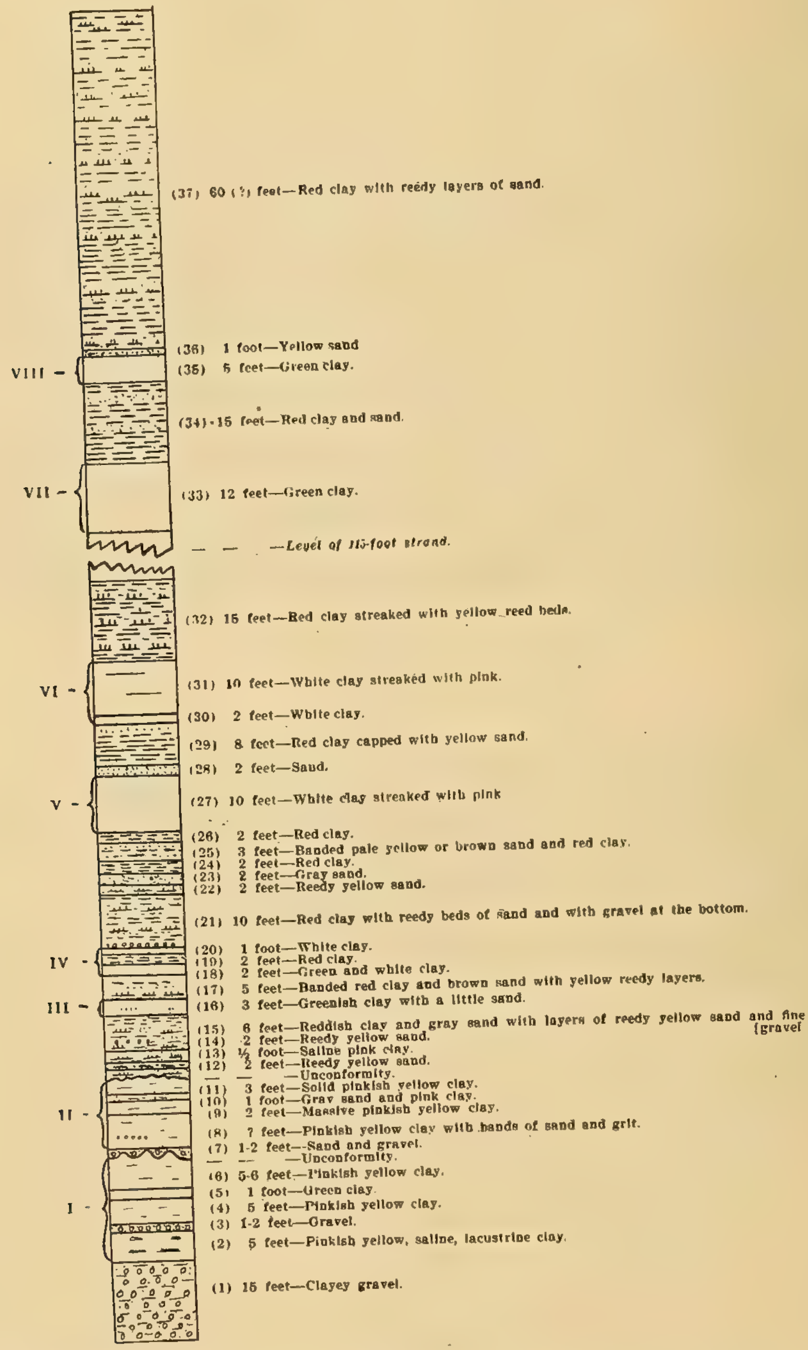

FIGURE 10.—*Section along the dry Stream Bed leading Southward from Altmish Bulak to Lulan.*

North of old Lop-Nor. The numerals on the left indicate lacustrine epochs. Scale: 1 inch = 40 feet.

stream after it had carved a channel in the soft clays numbered 1 to 4. Elsewhere along the sides of the modern gully where the section shown in figure 12 is exposed, the whole of the cross-section of the old channel can be seen. The channel is cut in clay and sand, and forms a typical fossil stream bed of gravel several hundred feet wide. Figure 13 shows how it happened that the old stream of figure 12 could cut so deep a channel. *A-B* seems to be a battered lacustrine bluff, cut by the lake when the water stood some 50 or 60 feet above the present level. The lake stood at this height long enough to cut a bluff resembling that of plate 32, figure 2. Later the water rose above the bluff at various times and the overlying strata were deposited.

It is impossible to assign a date to the fossil bluff of figure 12. It was certainly formed before the time of the 115-foot strand and probably before that of the 300- and 600-foot strands. As appears in figure 5, the strata above the unconformity consist of two deposits of semi-lacustrine and very saline red clay separated by 41 feet of subaerial deposits belonging to an unmistakable interlacustral epoch. The upper layer of saline deposits lies well above the 115-foot strand, and clearly antedates it. The lower layer of saline deposits is, of course, still older. It may be that the two were formed during the 300- and 600-foot epochs of lake expansion, although the red color seems to be against this. In the present ab-

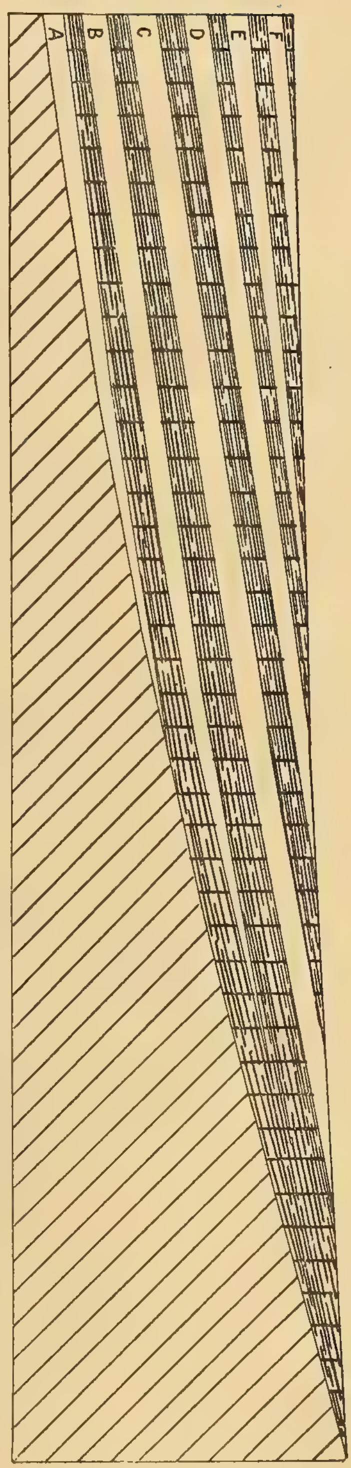

FIGURE 11.—*Diagram illustrating the Occurrence of Lacustrine and non-Lacustrine Strata on the Borders of old Lop-Nor.*
Unshaded areas = Lacustrine strata. Heavily shaded areas = Interlacustrine subaerial strata.

sence of knowledge, it is useless to carry the subject further. The point to be emphasized is that the unconformity, with its accompanying fossil stream channel and lake bluff, confirms the conclusion derived from a study of the alternating lacustrine and non-lacustrine strata. The conclusion is that during recent geological times there have been important

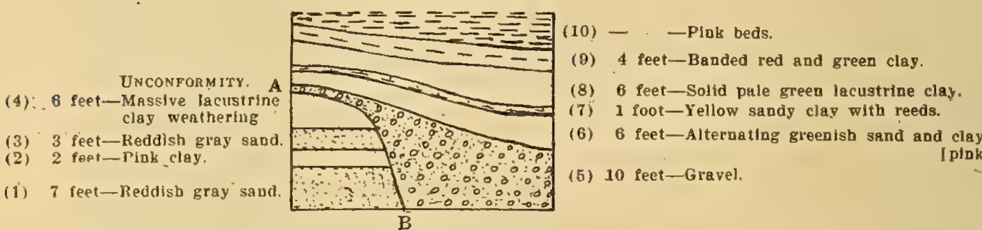

FIGURE 12.—*Section in Valley 2½ Miles East of Chindelik Spring.*

South of old Lop-Nor. Scale: 1 inch = 25 feet.

epochs of climatic change of which we obtain no hint from the study of glacial phenomena.

NUMBER OF CLIMATIC CYCLES IN THE PLEISTOCENE (PLIOCENE) STROPHE AT LOP

The exact number of lacustral epochs recorded at Lop-Nor can not be determined as yet. In figure 10 I have indicated 8, but other interpretations are possible. For instance, the epochs numbered I, II, and IV are each double. On the other hand, many observers would interpret III and

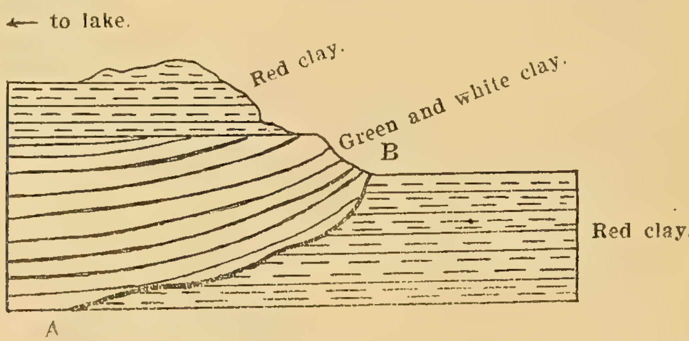

FIGURE 13.—*Cross-section of Eolian Mesa shown in Figure 2, Plate 36.*

Section is at right angles to old lake shore, and lies near figures 8 and 9, and at about the level of 9B, between the 35- and 115-foot strands.

IV as a single complex epoch. Thus the number of lacustrine epochs shown in this particular section is at least 7 and at most 11. The upper lacustrine layer may possibly have been deposited at the time when the lake stood at the 115-foot level, but there is no certainty in this respect. In like manner the two lacustrine layers next below, namely, numbers VI and VII, may represent the 600- and 300-foot lakes respectively. If we

FIGURE 1.—THE DESICCATED PLAIN

Villagers of Turfan digging ancient reed-stocks from the desiccated plain for firewood

FIGURE 2.—THE PLEISTOCENE (PLIOCENE) DEPOSITS

Petrified tree in the lacustrine deposits southeast of the playa of Turfan

THE BASIN OF TURFAN

suppose that this is the case, there still remain at least four lacustrine epochs preceding the five which can be correlated with the glacial epochs of Europe and America. If we go to the other extreme and make the number of lacustrine epochs as large as possible, we find that there is a possibility that there were eleven preceding the five known in other lands. Whichever interpretation we adopt, it appears that the Pliocene and Pleistocene strophic period was highly complex.

The Basin of Turfan, in Chinese Turkestan

GENERAL DESCRIPTION OF THE BASIN

At Turfan, 200 miles north of Lop-Nor, we find further evidence of complexity. Turfan is a small basin of the same type as Lop and Seyistan. Its aggraded floor extends about 100 miles east and west and 50 north and south. In spite of its extreme mid-continental position, the lowest point of Turfan lies two or three hundred feet below sealevel. Practically no rain ever falls on the basin floor. The high mountains to the north and west receive enough rain to support a few perennial streams too small to be called rivers. During the winter some of the streams reach the playa of Böjanti, in the center of the basin. There they form a thin sheet of water which dries up in summer. In spring, when the snow melts, floods from the mountains sink into the gravel and silt of the basin floor, and in the lower part convert scores or even hundreds of square miles into an impassable bog of deep mud. Vegetation springs up in the bog, but attains only a limited growth, as the country soon becomes parched. A few hundred years ago, when the rainfall was apparently larger, vegetation, chiefly reeds, grew far more abundantly. The plain is full of an amazing number of reed stocks in places where reeds can not now grow for lack of water. So abundant are the dead reeds that the villagers who utilize the streams for irrigation make a practice of digging out the dry stalks for firewood (see plate 35, figure 1).

The recent geological history of Turfan has been complicated by the upheaval of the Fire mountains during the Pleistocene period. This little range consists of a fault-block of red sandstone 5 or 10 miles wide and extending 50 or 60 miles east and west. It divides the floor of the Turfan basin into a northern third and a southern two-thirds. The front slope of the range takes the form of a steep red escarpment nearly 2,000 feet high, rising abruptly on the north side of the fault-line, which runs in an almost straight line east and west. The back slope toward the north is very gentle. The sandstone of the upfaulted block of the Fire mountains dips northward. The recency of at least part of the

faulting is evident, not only from the steepness of the escarpment and the narrowness of the gorges which traverse it, but from the fact that it cuts across terraces dating from the three arsial epochs corresponding, apparently, to the first three glacial epochs of Europe.

ABANDONED LACUSTRINE STRANDS OF TURFAN

In spite of the complications due to the upheaval of the Fire mountains, there remain on the south side of Turfan various evidences that the climatic history of the region has been the same as that of Lop-Nor. It could hardly have been otherwise, for at the time of greatest expansion the borders of the lakes of Lop and Turfan were only a little over a hundred miles apart. South of the playa of Böjanti, in a region where there appear to have been no notable earth-movements during recent times, two sets of old lake bluffs can be recognized. One lies only a few feet above the floor of the playa. It may correspond to either the 20- or 35-foot strand of Lop-Nor. The other set of bluffs lies far back from the playa and is almost completely shrouded in piedmont gravel. Its base appears to lie at an elevation of between 100 and 200 feet above the playa, but so much debris has been washed in from the upper parts of the bluffs that the actual base is everywhere deeply buried. Judging by the appearance of the bluffs, they must be at least as old as the 300-foot strand at Lop-Nor. Further study would probably reveal other strands corresponding to the five epochs of which such abundant evidence is found in other parts of central Asia. My stay in the region was too short for more than the most cursory examination. I found, however, that many of the valleys of Turfan are characterized by five fluvial terraces like those of the Lop basin, Russian Turkestan, and Persia.

PLEISTOCENE (AND PLIOCENE) DEPOSITS OF TURFAN

1. *Lacustrine layers.*—The upper bluff at Turfan is cut in unconsolidated clays. The succession of strata is shown in figure 14. The section is far from complete. Upward it is prolonged by reddish deposits containing more or less sand and deeply shrouded in gravel. Downward it continues indefinitely. The highest deposits lie 250 feet above the playa, and the lowest almost at its level. The section here shown, however, covers only 110 feet. Three unmistakable lacustrine layers are evident. All three are older than the upper bluffs, and two at least appear to be older than the oldest strand at Lop-Nor. Here, as elsewhere, we find some evidence of epochs of climatic change preceding those recognized in glaciated countries.

2. *Vegetal layers.*—An examination of the details of the Turfan section discloses the fact that there are practically no red strata. Their

place is taken by layers of dark carbonaceous clay, bog iron ore, and lignite. Manifestly these layers are of subaerial origin, or at least were formed in very shallow water, such as that of the swamps of Seyistan and Lop, or the flood-plains of the same regions. Vegetation was abundant, as has been the case till recently. Even now the vegetation of the plain of Turfan is more flourishing than that of the plain of the Lop basin. In ancient times, when the lignite and carbonaceous clay of the section were formed, much of the vegetation was probably a low, swampy growth, but there were plenty of trees also. In and near the carbonaceous layers I found many pieces of fossil wood containing much iron. The trunk shown in the photograph (plate 35, figure 2) was preserved intact for a length of about 8 feet. It was a foot in diameter and was somewhat flattened. Its preservation was so perfect that the scars where the branches had been broken off were intact. The interlacustrine strata of Turfan reproduce the essential features of the vegetal beds of the Carboniferous period. The section given in figure 14 resembles sections in the Coal Measures of Pennsylvania.

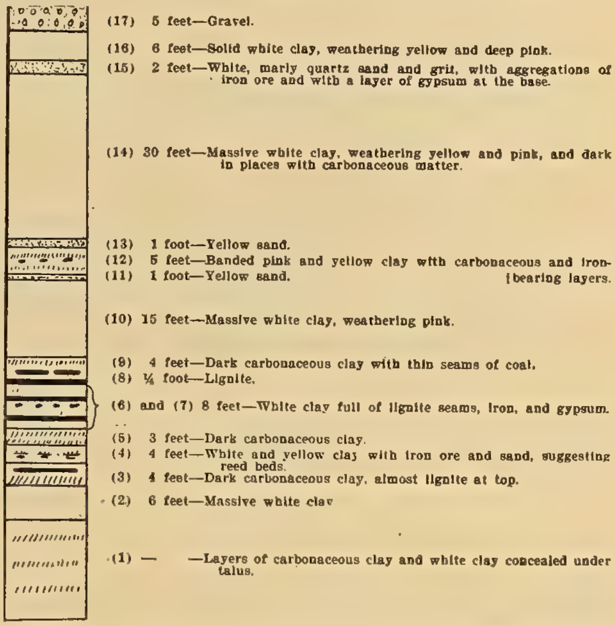

FIGURE 14.—*Lake Deposits and Quaternary Coal Measures at Tatlik Bulak.*

Southeast of the playa of Turfan. Same scale as figures 5-10. 1 inch = 40 feet.

Apparently on the advent of an interlacustrine or thesial epoch, the lake of Turfan contracted, leaving a smooth plain. Streams from the mountains—then much more than now—kept the plain moist. The result was a luxuriant growth of vegetation, not only on the immediate edge of the lake, but in large areas of swampy land round about. When conditions were most favorable, plants grew so luxuriantly that thin beds of lignite were formed. Under less favorable circumstances, the number of plants diminished, more or less detritus was washed into the swamps, and carbonaceous clays were formed. Sometimes the bogs produced iron ore; again, trees grew in the swamps or were washed in from the surrounding

uplands. Under other conditions reed beds flourished. During a single prolonged interlacustrine epoch many minor variations of climate appear to have taken place, so that the strata exhibit much variety. The variations can hardly have been due to movements of the earth's crust, for there is no sign of erosion or of the unconformities which would probably have been formed under such circumstances. Moreover, the fact that in spite of highly complex changes, involving constant repetition of a varied series of events, the history of Turfan agrees with that of distant regions, such as Lop and Seyistan, argues in favor of some widespread cause such as worldwide changes of climate.

Throughout the epochs shown in figure 14, the climate seems at all times to have been moist enough so that plants grew vigorously. Even when coal or carbonaceous clays were not deposited, there were plants enough to leach out from the deposits their oxidized iron as fast as it was formed. The absence of red color seems to demand this explanation. During later thesial epochs, however, red strata were deposited, as we find in the almost concealed layers lying above those shown in the section. Hence we may infer that during some of the more severe thesial epochs the climate of Turfan became so dry that plants ceased to flourish and iron oxide accumulated with nothing to take it out.

COMPARISON OF THE PLEISTOCENE VEGETAL LAYERS OF TURFAN WITH MESOZOIC COAL BEDS

The very recent interlacustrine vegetal layers described above are not the only ones at Turfan. At the base of the faulted and tilted strata exposed in the gorges of the Fire mountains workable coal is exposed. It is probably of Cretaceous age, but this is not certain. The section, as seen in the Lemjin gorge, a few miles north of Lukchun, is as follows:

(10) A great thickness of fine-grained, sandy, red silt or shale, full of lenses, mud cracks, and other signs of subaerial origin (see plate 36, figure 1, and plate 39, figure 1).

(9) Transitional beds, showing a gradual change from the underlying pure green shales to the overlying sandy red shales. The transitional beds consist of an intimate mixture of layers of red and green and purple of all thicknesses from an inch to 5 or 10 feet. At the bottom, green beds predominate, and at the top, red.

(8) Several hundred feet of green shale.

(7) Thin coal seams.

(6) 30 feet of green shale.

(5) 20 feet of coal measures, with seams of bituminous coal from 1 to 8 inches thick, some of which are worked. The rest of the 20 feet consists of carbonaceous shales and of thin partings of iron ore.

(4) 100 to 200 feet of green shale.

(3) A workable layer of coal.

(2) Soft whitish shales.

(1) Yellowish green shales.

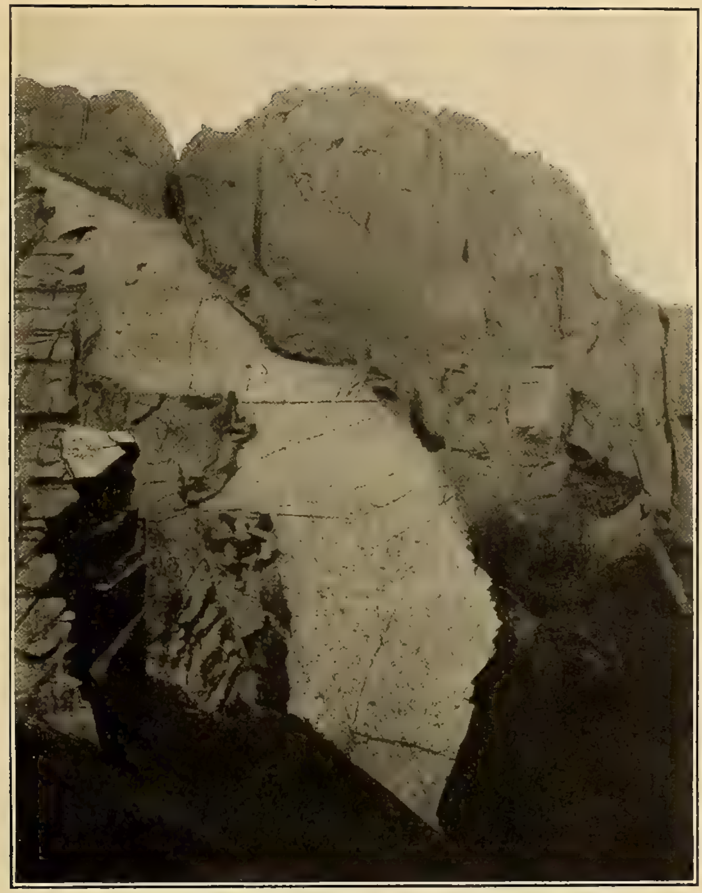

FIGURE 1.—A MESOZOIC AQUEOUS FORMATION

The subaerial strata of the Fire mountains, in the Tuyok valley of Turfan, showing a layer in formation 10 of page 378. The upper half is ripple-marked and the lower mud-cracked

FIGURE 2.—A MODERN ÆOLIAN FORMATION

Cross-bedded æolian sand at the northern base of the Kwen Lun mountains, south of the Takla-Makan desert

TYPES OF SUBAERIAL DESERT DEPOSITS

It will readily be seen that the essential features of the Mesozoic coal measures are similar to those of the Quaternary vegetal layers found among the lake deposits. The Mesozoic coal appears to have been deposited in swamps resembling those in which the lignite of recent times was deposited. The ancient swamps were probably like the muddy plain of today, except that water was more abundant and vegetation more luxuriant. The green shales, in the midst of which the coal measures lie, were evidently deposited in a large body of standing water, either the sea or a lake. No fossils have been found by which the nature of the body of water can be determined. The very fact, however, of the absence or rarity of fossils in shales so well adapted to their preservation argues against marine conditions. Continental conditions certainly prevailed immediately before the deposition of the main body of green shales of formation number 8, as the vegetal character of the coal measures proves. They also prevailed immediately after the deposition of the green shales, for the latter pass by gradual and almost imperceptible stages into the typical subaerial strata of the formation numbered 10, full of thin lenses, mud-cracks, ripple-marks, and other signs of deposition in very shallow water, which covered the country at certain seasons only, leaving it dry the rest of the time (plate 36, figure 1, and plate 39, figure 1). In view of these facts, it is not improbable that the green shales of Turfan were deposited in a large lake. If this is so, they, together with the interbedded layers of coal, probably preserve the record of a strophe during which the lake contracted during thesial epochs, permitting the growth of vegetation. Similarly the alternating red and green strata at the top of the green shales suggest a strophic period at the end of which there had been such a change in the continental form of central Asia or in the climate that the lake of earlier times disappeared.

Characteristics and Origin of Red Strata

1. *FEATURES INDICATING SUBAERIAL ORIGIN*

Red beds have been spoken of above as indicating aridity and as indicating subaerial conditions of deposition. It is not meant by this to imply that there are no red beds which are of marine origin or which were deposited under humid conditions. It appears probable, however, that red beds of the kind here described are subaerial, and that the color indicates aridity during at least part of the year. Although reasons for this view have already been given, it seems advisable to restate them more fully. Many red strata are characterized by frequent changes of texture or structure. Such has been the case wherever I have examined

them in the United States, Persia, Russian Turkestan, and Chinese Turkestan, and they are so described in many other places. In typical cases layers of fine sand alternate with those of silt or clay; most of the layers die out if followed far; many can be seen at a glance to be lenticular; lenses of relatively coarse material often interrupt finer beds, and everywhere there is lack of uniformity in minor details, although the formations as a whole may appear massive and homogeneous. All these features, as Davis has shown in his papers on the Tertiary deposits of the western United States, indicate that the strata were deposited under very changeable conditions highly inconsistent with a marine or lacustrine origin, but eminently consistent with a subaerial origin. Varying deposits of this sort may perhaps be laid down in the littoral zone of estuaries; but such a supposition is out of the question in the cases under consideration, because of the vast extent of the red deposits and because they are not found to merge into marine deposits. The red strata of central Asia appear to extend over an area 1,000 miles long from east to west.

Other evidences of subaerial origin are found in common features such as mud-cracks, ripple-marks, rain-drop prints, and the tracks of terrestrial animals. These indicate that the regions of deposition were flooded at intervals, but were exposed to the air a large part of the time. Barrell* has shown conclusively that only a small fraction of such markings can have been formed upon tidal flats; the great majority must have been formed in deltas, playas, and flood-plains, chiefly in arid regions.

2. *FEATURES INDICATING ORIGIN UNDER ARID CONDITIONS*

Having concluded from the features mentioned above that many red strata are subaerial in origin, we must inquire into the evidence as to the kind of climate which prevailed at the time of their formation. It is well known that in the world today subaerial deposition is in progress chiefly in arid regions, and therefore, on general principles, subaerial strata of former times, whether red or of some other color, are likely to have been formed in arid regions. The red beds, however, contain direct evidences of aridity. One of the commonest and most universally recognized is intercalated beds of gypsum, indicating shallow, saline lakes. Another is eolian cross-bedding of a type which can not, apparently, be produced by water. Its chief characteristics are the comparative uniformity in size of the sand-grains in which it is found, the frequent tangency of the individual beds to the floor on which they lie, and the large scale of the

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* Joseph Barrell: Relative geological importance of continental, littoral, and marine sedimentation. Journal of Geology, vol. xiv, 1906.

FIGURE 1.—MODERN FLUVIAL AND ÆOLIAN BEDS

Cross-bedded æolian sand, lying upon the fluvial gravel of a typical climatic terrace at the northern base of the Kwen Lun mountains. They show how fluvial and æolian strata may be interbedded. On the left the cross-bedded layers not only overlie fluvial deposits, but are capped by other fluvial deposits—fine clay, which breaks off in lumps

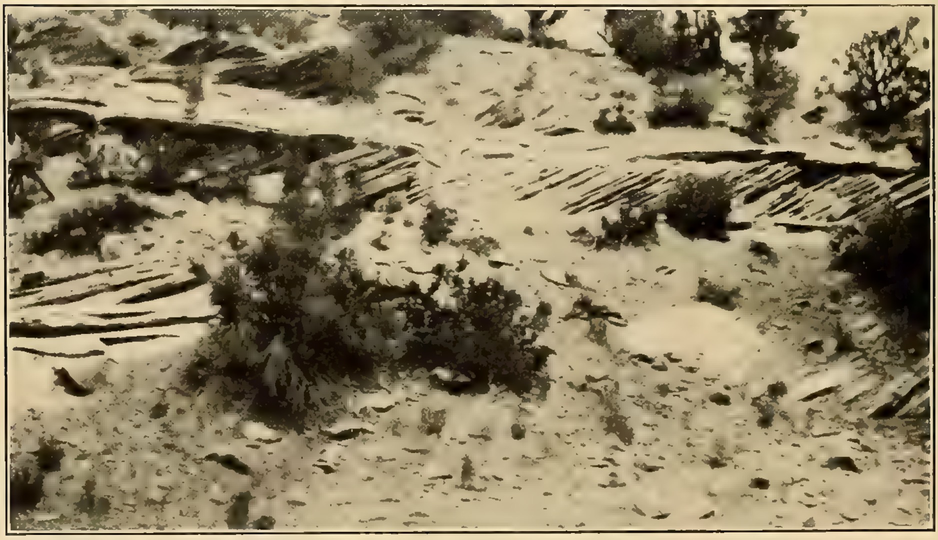

FIGURE 2.—MESOZOIC ÆOLIAN BEDS

The white Colob (Jurassic ?) sandstone of Utah, near Kanab

TYPES OF SUBAERIAL DESERT DEPOSITS

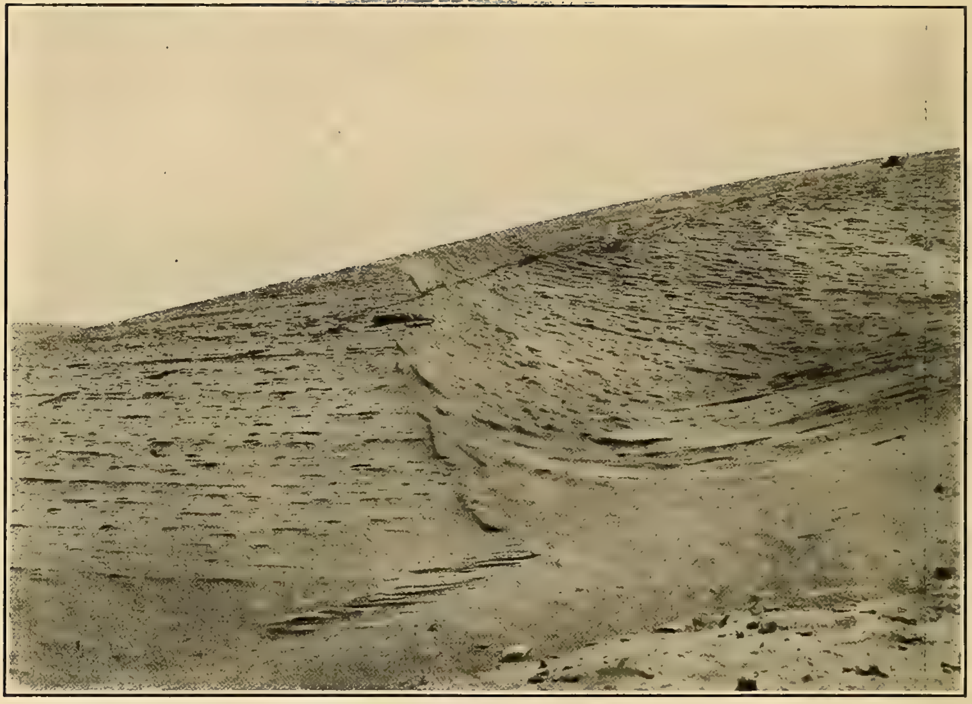

FIGURE 1.—CROSS-BEDDING IN THE DUNES OF SEYISTAN

The scale may be judged from the hat. These dunes move with extraordinary rapidity, objects 10 or 12 feet high being buried and exposed again in a single year

FIGURE 2.—DETAIL OF CROSS-BEDDING AT SEYISTAN

Showing the tangency peculiar to æolian deposits

AEOLIAN DEPOSITS IN PERSIA

cross-bedding. Among the modern sand dunes of Persia, Transcaspia, and Chinese Turkestan these features are frequently seen, as appears in the photographs of plates 36, figure 2; 37, figure 1, and 38. Among ancient deposits, they are finely exemplified in Utah in the massive red sandstone of the Kanab formation and the white sandstone of the Colob (plate 37, figure 2). They appear occasionally in the red sandstone of various ages found in Turfan, the Lop basin, and Russian Turkestan. Cross-bedding of the type here considered seems to be strong evidence of both subaerial and arid conditions.

Another indication of aridity in red beds is their relation to fossils. In general, fossils are absent, and where they occur they usually appear to be of terrestrial types. Barrell has shown that in many cases the few plants of which traces can be found in red beds are adapted by their long roots and other characteristics to arid conditions. He has also shown that in subaerial strata redness is not consistent with the continued presence of ground water. Where the ground is always saturated the plants leach out the oxidized iron from the soil as fast as it is formed; hence the soil can not become very red. Where there are no plants, on the contrary, the oxidized iron remains in the soil, which, if long exposed to the air, becomes red, unless, indeed, it happens to be highly quartzose or for some other reason contains little iron.

A good example of the relation of redness to the presence of water impregnated more or less with carbonic acid and other vegetal products has been called to my attention by Mr R. W. Sayles. In the Medina formation, below Niagara Falls, the small faults which characterize the region are brought into prominence by the fact that on either side of them the red sandstone for an inch or so has been leached of its iron, and is of a greenish tint. In other words, the presence of water which has reached the fault fissures after passing through the atmosphere and through a layer of vegetation, serves to nullify the conditions which originally produced the red color. The obvious inference is that when the red strata were formed no such water was present. Unless the climate was arid at the time of the deposition of the Medina, such water must have been present, whether the strata are of estuarine, or, as seems more probable, of subaerial origin.

A final reason for believing that redness is in many cases the result of aridity is found in certain observations which I made in the deserts of Transcaspia in Russian Turkestan, and of Takla-makan, from 1,200 to 1,500 miles farther east, in Chinese Turkestan. These deserts, especially the latter, are far more arid than the deserts of America. They are

not clothed with scraggly bushes, and their dunes are not mere little heaps of sand 5 or 10 feet high. In the Takla-makan desert one can travel scores of miles without encountering the slightest trace of vegetation, either dead or living. One travels there day after day over dunes from 100 to 200 feet high, and occasionally over dunes which rose to heights of 400 and even 500 or 600 feet, veritable mountains of sand. To climb over a single one, about 400 feet high, took the camels of my caravan nearly two hours. The Transcaspian desert is less rigorous than the Takla-makan, but nevertheless it is a genuine desert.

Along the edges of both deserts there are vast piedmont slopes of gravel, sand, and silt washed down from the mountains. These are constantly being built up by the deposits of streams and as constantly worked over by the wind. The finer materials are wafted away as dust, to be deposited upon the uplands in the form of loess, while the sand is heaped into dunes. Near the edges of the deserts the sand is usually white, yellow, or pale gray, like that of ordinary beaches. Farther out, however, as one gets away from the regions of recent deposition, it changes gradually to a distinct pink color. I saw this transition many times, especially in the Takla-makan desert. It is so common a feature that among the natives the term "kuzzil kum," or "red sand," is used to denote the real desert, the region of great dunes and of no water or plants. More than once, when I asked about traveling in a certain direction, I was told, "You can't go there. It's red sand." The pink sand of the central parts of the desert appears to be of precisely the same origin as the yellow sand of the edges. The only difference is that it is of finer texture, and that its oxidized iron has been dehydrated, thus changing its color. The cause of the redness of hundreds of miles of sand in the Takla-makan and Transcaspian deserts, and also in Arabia, where similar conditions are reported, is apparently the aridity of climate, which allows the sand to be long exposed to the air without the presence of plants.

In view of all the facts, it seems highly probable that many of the great non-fossiliferous red deposits of the earth which do not contain marine fossils have originated under subaerial conditions, where the climate was very dry, at least during certain seasons.

Summary of Conclusions as to the Pleistocene climatic Strophe

In the study of the Pleistocene climatic strophe as a whole, it appears that the investigation of glacial phenomena can best be supplemented by

an inquiry into the phenomena of arid regions. In such regions the most obvious features due to change of climate are lacustrine strands. These are well marked in the three basins of Seyistan, Lop, and Turfan, and also in other basins of central Asia not here discussed. They do not differ essentially from the classic examples of lakes Bonneville and Lahontan. Where best developed, in the Lop-Nor region, they number five main strands and a sixth minor one. Between the glaciers of the upper parts of the streams and the lakes at the other extremity, the river valleys of central Asia are characterized by terraces, apparently of climatic origin, which agree in number and size with the moraines at one end and the strands at the other. The terraces are of high importance because, if they have been rightly interpreted, they preserve a record of the changes of the Pleistocene strophe not only in central Asia, but in other arid regions, such as northern India, the Deccan, and the basin region of the United States. Both terraces and strands, important as they are, suffer from the same limitations as do moraines. They afford an incomplete record, because the work of less severe epochs is liable to effacement during later epochs of greater severity.

The records of climatic change preserved in the alternating lacustrine and subaerial deposits of the bottoms of inclosed basins suffer from no such limitations; they are complete; hence their great importance in the few places where they are exposed. A study of the three basins of Seyistan, Lop, and Turfan shows that the depositional records of a climatic strophe in the bottoms of basins comprise at least two main types of alternating strata. The first consists on the one hand of greenish or light colored layers of lacustrine origin, and on the other of reddish subaerial layers, the color of which indicates that they were deposited under conditions of great aridity. The second consists of lacustrine layers alternating with subaerial vegetal layers, which indicate the presence of swamps at times when the lake contracted.* Both types of strata show that in central Asia the Glacial period was a time of oscillations between epochs of abundant water supply and those of aridity, during which the water supply was as small or smaller than at present. This would naturally be expected from what has been learned of the Glacial period in other parts of the world. A more unexpected result is found in the evidence of the three basins as to the length and complexity of the Pleistocene strophe. It appears that, in central Asia at least, the strophe consisted of a large number of cycles, part of which preceded those known elsewhere as the Glacial period. Apparently the entire strophe consisted

* A third type of formation indicative of climatic change ought to be mentioned, namely, alternating strata of gravel and of finer materials. It has been so little studied that it is omitted above.

of a considerable number of cycles of increasing severity or length, tending toward a maximum, after which there ensued the well known series of cycles of decreasing severity.

Comparison of the Pleistocene and Permian Strophes

The Pleistocene is not the only strophic period recorded in geology. The most widely known of the others is that which occurred at the end of the Carboniferous or beginning of the Permian. This period, to quote Chamberlin,* was marked by a "glaciation the deposits of which aggregate a greater thickness than those of Pleistocene times, and whose oscillations, marked by accumulations of coal, were even more remarkable than those of the Pleistocene glaciation." In addition to glacial beds, there appear to be, as has been said above, at least two other great types of strophic deposits, namely, alternating vegetal and non-vegetal strata, and alternating layers of red subaerial strata and of green or white lacustrine strata. If deposits of all three types were produced during the Pleistocene strophe, it is highly probable that they were also produced during the greater Permo-Carboniferous strophe. Deposits of the first two types, glacial and vegetal, are already well known from the Permian or Carboniferous beds of India, Australia, and South Africa. It is probable that further study will disclose one or the other in various parts of the world.

Inasmuch as the third type, alternating red and green strata, has hitherto not been recognized as indicative of strophic conditions, attention has naturally not been called to it in connection with the Permian.

Possible climatic Significance of the Red and White Moencopie Shales of Utah

In the desert county north of the Colorado canyon, in northern Arizona and southern Utah, the Aubrey limestone, a formation well established as of Carboniferous age, is capped by about 1,000 feet of variegated shales and sandstone, chiefly red, as shown in the accompanying sections (figures 15 and 16,‡ and plate 39, figure 2). These Moencopie strata contain no fossils, so far as is known, except at the base in the transitional beds overlying the Aubrey. They have been called Permian because of their stratigraphic position. It has generally been assumed that they are of marine origin, but there is no proof of this. In describing them in a paper on the "Hurricane Fault,"† Professor J. W. Goldthwait and the

* T. C. Chamberlin: An attempt to frame a working hypothesis of the cause of Glacial periods on an atmospheric basis. Journal of Geology, vol. vii, 1899.

† Bulletin of the Museum of Comparative Zoölogy at Harvard College, Geological series, vol. vi, no. 5, 1904.

‡ *Note to figures 15 and 16.*—The sections shown in these figures are not exact in details beyond what is shown by the printed list of formations. At the time when the sections were studied their importance was not realized.

FIGURE 1.—AN EXAMPLE FROM CENTRAL ASIA

Subaerial or continental strata of the Fire mountains in the Tuyok valley of Turfan, showing lenticular white layers of shale and gypsum in the midst of red strata on the left, and thicker layers of white or pale green shale, alternating with red, on the right above

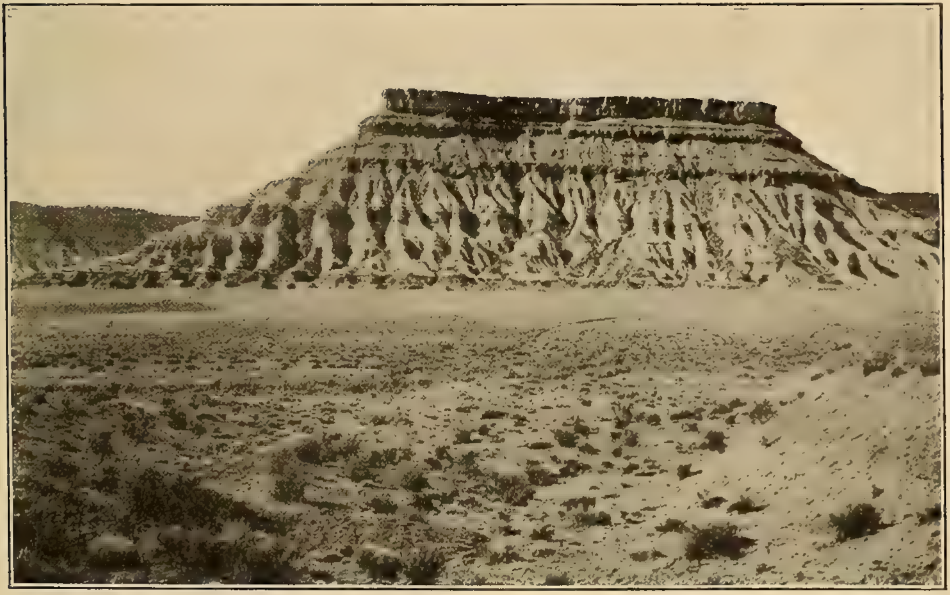

FIGURE 2.—AN EXAMPLE FROM THE UNITED STATES

Mesa of red and white Moencopie shales capped with Shinarump conglomerate, in southern Utah. Photograph by W. M. Davis

RED AND WHITE CONTINENTAL DEPOSITS

writer came to the conclusion that "the Moencopie series was probably laid down in a shallow sea where estuarine conditions may possibly have prevailed, as is indicated by the intercalated layers of gypsum and the almost total lack of fossils in strata admirably adapted to their preservation had they existed." The estuarine origin is extremely doubtful, however. It is probably inconsistent with the red color and with the numerous changes in the character of the strata. The beds as a whole present a large number of the features which have been described above as characteristic of subaerial deposits laid down under arid conditions. They are capped by the Shinarump conglomerate, the fossil trees of which prove it to be of subaerial origin. The middle part of the Moencopie shales consists of a large number of alternating red and white layers. The red portions appear to be of subaerial origin, to judge from their color and from the frequent changes of texture to which they are subject. The white appear to have been deposited in standing water.

If the red and white layers respectively originated subaerially and in somewhat

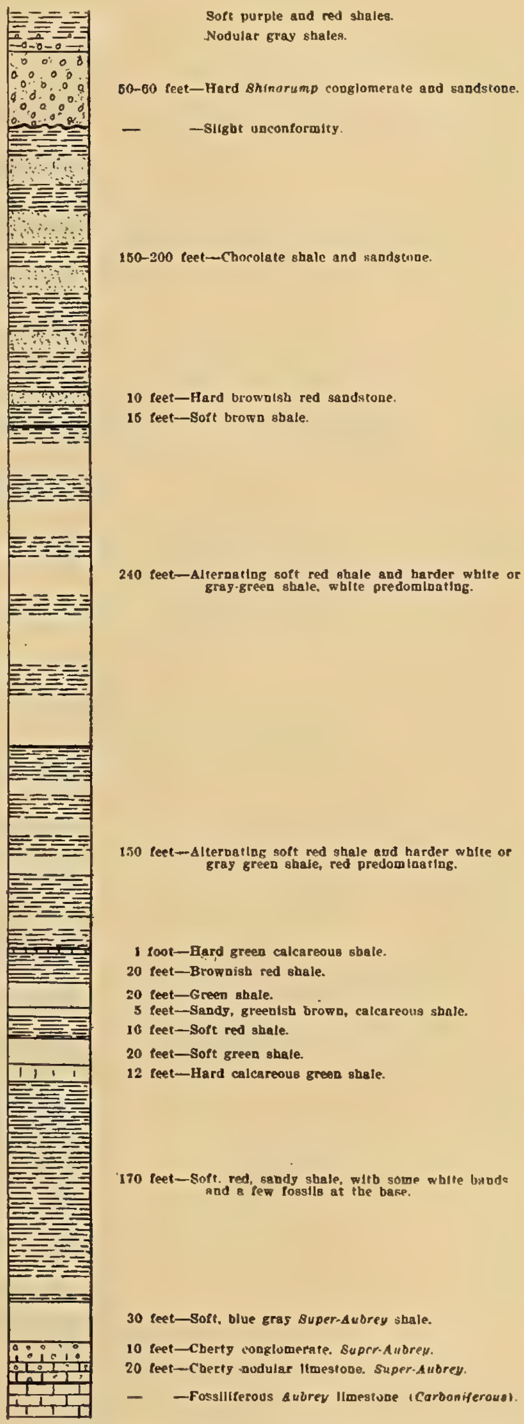

FIGURE 15.—*Section of the Moencopie Shales at Dry Creek, near Toquerville, Southern Utah.*

The scale of this figure and the next is one-fourth that of figures 3-10 and 12-13. Scale: 1 inch = 160 feet.

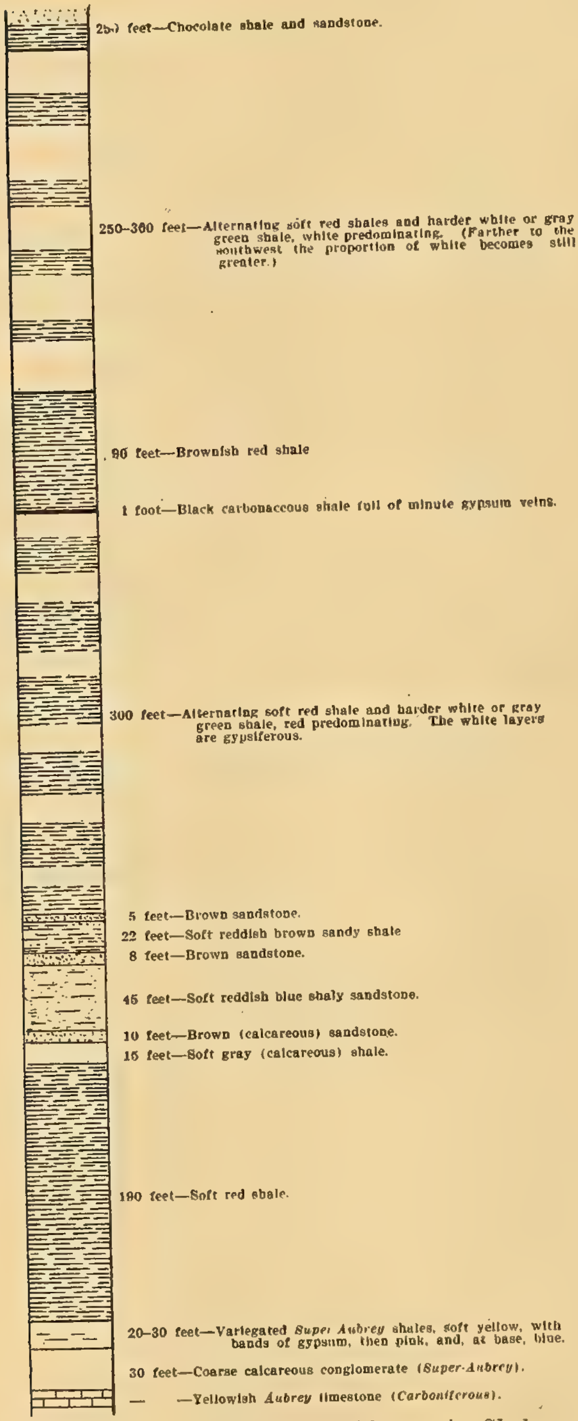

FIGURE 16.—*Section of the Moencopie Shales near Virgin City, Utah.*

Virgin City is near the western end of the southern border of Utah, 12 miles south of the locality represented in figure 15. Scale: 1 inch = 160 feet.

permanent bodies of standing water, two hypotheses present themselves: Either the white layers indicate successive brief encroachments of the sea, or they preserve the record of a strophic period during which parts of the floor of an inclosed basin were alternately exposed to the air and covered by the waters of a lake. According to the first supposition, the land moved gently up and down time after time, or, more probably, sank by steps. At first a given area was above sealevel and was covered with red deposits; then, perhaps because it had become loaded with sediment, it sank slightly below the sea. Deposition still proceeded, though now the deposits were of a light color. At length they accumulated so that their top reached the surface of the sea; thereupon the deposits became red, and so continued until the land sank again, and the process was repeated.

This hypothesis, postulating, as it does, that the land sank by steps, is generally accepted in explanation of the alternation between coal measures and barren measures. As

applied to the Moencopie shales, it involves the following assumptions: First, the sea must have been almost tideless, for there is no evidence of the erosion which the rise and fall of the tides would occasion; second, the sea must have been almost devoid of life; third, there must have been a remarkable series of earth-movements, whereby at subequal intervals the land was again and again depressed, so that the surface time after time stood at practically the same depth below sealevel.

The first two assumptions present no special difficulties, although to-day we know of no tideless, lifeless sea of the kind demanded. The third assumption presents greater, although not insuperable, difficulties. It demands that a large number of downward movements of the earth's crust should have been of such dimensions that each one depressed the whole of an area of hundreds of square miles to essentially the same depth of a few feet below sealevel; that is, the successive movements always carried the surface down just far enough to let it be covered by the sea, but never far enough to let it be submerged more than a score or two of feet. For some reason, the level of the sea determined the amount of movement of the earth's crust, although there seems to be no good reason for the existence of any such relation.

The hypothesis that the alternating red and white strata preserve the record of a strophic period during which a lake alternately contracted and expanded presents no such difficulties. The Moencopie shales closely resemble the Seyistan clays, and the two may represent corresponding phases of the Permian and Pleistocene strophes. If this is so, the Moencopie land on its emergence from the Carboniferous sea must have been warped into a flat-floored basin. At first subaerial deposition apparently prevailed, but later, on the advent of the changeable conditions of a strophe, lacustrine conditions prevailed during arsial epochs, and the basin floor was exposed to subaerial deposition only during thesial epochs.

America is not the only part of the world where alternating red and white strata of Permian age are found. In Arabia, Palestine, Sinai, and Nubia there is a thick body of non-fossiliferous strata, chiefly composed of red sandstone. This "desert sandstone," as it is called, lies conformably between a thin bed of limestone containing *Productus* and other Carboniferous fossils and a thick limestone full of Cretaceous fossils. Its lower portion, which occupies the stratigraphic position of the Permian, is said by Lartet to contain layers of shale and marl. Hull says that near mount Sinai "the lower beds are generally white, succeeded by red, and these by yellowish strata. . . . Language almost fails to convey to the reader an idea of the effect produced [at Petra] by the alternations of yellow, orange, red, and purple tints, of varying depths,

and arranged in parallel bands."* The upper beds are "dark red, purple, and brown." Judging from the somewhat meager descriptions, the lower part of the "desert sandstone" closely resembles the Moencopie formation. It seems not improbable that both sets of strata were deposited under the changing climatic conditions of the Permian strophe, and that both owe their peculiar character to the fact that they were formed in large desert basins of the same type as those of Lop and Seyistan. If this interpretation shall prove correct, it may be found that the records of the Permian strophe are as complete and as remarkable to the north of the equator as to the south.

* Edward Hull: Mount Seir, Sinai, and western Palestine, pp. 53-54.

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A THEORY OF CONTINENTAL STRUCTURE APPLIED TO NORTH AMERICA*

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(*Presented in abstract before the Society December 29, 1906*)

CONTENTS

Introduction

For the purpose of this article the continent of North America may be described as that portion of the lithosphere which lies between the Atlantic, Arctic, and Pacific oceans or between their suboceanic masses. Its area is that of the continental platform. Its depth may be taken at approximately 100 miles, the probable average limiting depth of the zone of isostatic adjustment according to Hayford.†

This continental mass is of large dimensions and exhibits at its surface such variety of terranes and such diversity of geologic effects as to indicate beyond any reasonable doubt a heterogeneous constitution. Contrast the Canadian highlands with the Mississippi embayment, the Atlantic coastal plain with the Pacific Coast ranges, the New England metamorphic province with the Allegheny plateaus, the volcanic belt of the Cordillera with the non-volcanic regions of the East.

*In reading this article it is desirable to consult the geologic map of North America issued for the Geologic Congress at Mexico, 1906.

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†O. H. Tittmann and J. F. Hayford: Geodetic operations in the United States, 1903-1906: A report to the fifteenth general conference of the International Geodetic Association. Washington, 1906.

Heterogeneity may be a condition inherent to some extent in original constitution, the term original being used to describe a constitution which has characterized the continent since a time at least as remote as any of which the rocks afford a record; and heterogeneity may also be an effect of terrestrial forces acting, as by intrusion, to modify the original structure.

To discuss a possible original structure and to define some of the conditions which have affected modifying forces are among the purposes of this paper. In order that the argument may be followed more readily, the hypothesis which has resulted from the investigation is here briefly stated.

Hypothesis of continental Structure

1. It is postulated that the continental mass which we call North America is heterogeneous, and that the unlike parts of it are of notable size, varying from a few hundred square miles in superficial area to subcontinental dimensions. These parts are referred to as elements of the continent, or continental elements.

2. The distinction between the continental elements is based upon their behavior during vertical movements, it being held to be demonstrable on the evidence of erosion or sedimentation that certain masses have shown a tendency to rise, whereas others have shown a like tendency to subside. The boundaries of the elements are accordingly indicated where conditions of general denudation pass into conditions of long-continued aggradation, either subaerial or submarine.

It follows that those continental elements which have tended to rise are recognized by the unconformities or absence of sediments resulting from conditions of erosion, whereas those elements that have tended to sink are recognized by the accumulation of sediments upon them.

According to their diverse tendencies with reference to relative vertical movement, the two types of elements may be distinguished as positive or negative. Those which have shown a decided tendency to rise are designated positive elements, and those which have tended to sink are termed negative elements.

3. It is observed that uplands of erosion and lowlands of aggradation are commonly joined by a monoclinal flexure, which in some places involves a normal fault. When the region is altogether under subaerial conditions the flexure constitutes a warped surface, which is a mountain slope. Such is the descent from the Blue ridge of Virginia to the Atlantic coastal plain. Or, when the sunken region is so situated as to become an arm of the sea, the flexure is the locus of a coastline and the depressed

area becomes a basin of marine sedimentation. Such was the coastline of the Paleozoic mediterranean in the Appalachian province.

4. It is deemed probable that the continental elements differ in density among themselves and also in comparison with the suboceanic masses, this difference being an original character in the sense that it has distinguished the individual masses as far back in geologic history as the record of erosion and sedimentation is intelligible, and probably much farther back.

5. There have been horizontal movements as well as movements in a vertical direction. The horizontal displacements are of notable magnitude, and their effects are seen in the schistose structure of the once deep-seated rocks and in the overthrust and folded structures of the more superficial strata.

6. An effect of horizontal movements has been to crowd the continental elements together, and consequently to cause a certain amount of mashing in their deeper-seated portions. Just how the shortening may be distributed below the superficial crust which we can observe, we do not know; but from the universal occurrence of schistosity in rocks exposed by profound erosion, it seems probable that the compression is not far from uniform. On the other hand, at the surface there are diversities of structure and attitude which have served to concentrate the effects of horizontal displacement in certain zones, namely, in zones where sedimentary rocks had accumulated to considerable thickness.

7. The concentration of the effects of horizontal thrust in zones of sedimentary rocks is due to: (*a*) stratification, which determines the arrangement of material in extended sheets that are capable of moving over one another, and consequently of folding with comparative ease; (*b*) the deflection of the strata from a strictly flat attitude in such manner that initial lines of flexure are established, on which primary anticlines and synclines are later developed.* This initial deflection results from unequal subsidence during the process of deposition.

8. Recalling that coastlines are established along the monoclinal flexure which joins a rising with a sinking continental element, and that sediments accumulate to greatest thicknesses usually in a zone parallel to the coast, we see that zones of folding are commonly coastal zones. Since progressive subsidence results in the development of initial dips in lines essentially parallel to the coast, and since initial dips determine the axial directions of folds during the next epoch of deformation by horizontal stress, it follows that the axial directions of folds conform to the general

* Mechanics of Appalachian Structure. Thirteenth Ann. Report U. S. Geol. Survey, pp. 253-258.

contour of the higher continental elements. Furthermore, since these elements are the masses against which the strata are pressed in the process of folding, they are enveloped by the folds for that reason also.

Thus the axial directions of folds, the Leitlinien of Suess, constitute criteria for the analysis of continental structure, which are scarcely second in importance to unconformities and deposits.

9. There is abundant evidence in the broad relations of structure of North America, Asia, and Europe to prove that the tangential pressures exerted upon the continents proceed from the denser submarine masses. The theory here presented is that these pressures are due to what may be called *suboceanic spread*—that is, to the expansion of suboceanic masses, say, 100 miles deep, at the expense of subcontinental masses, in consequence of the efficiency of stress due to greater density to direct movements occasioned primarily by molecular or mass changes under varying conditions of temperature and pressure. The general result is plastic* flow in rigid and solid rock masses. It is further held that in the great suboceanic regions such flow is a persistent condition, to which we may ascribe those accumulated stresses that have sufficed to produce the occasional pronounced effects of diastrophism.†

10. It is held to be demonstrable, on the evidence of sequences and volumes of sediments, that the tendencies toward diverse vertical displacement of the continental masses have been effective in producing movement only during relatively short epochs between long intervals. Between the epochs of active displacement the tendencies toward movement were relatively ineffective. Hence we may recognize cycles of diastrophism, each one of which comprises (*a*) a comparatively brief epoch of orogenic and epeirogenic activity, which results in elevated lands and restricted mediterraneans, energetic erosion and voluminous terrigenous sediments, and climatic and faunal diversities; and (*b*) a comparatively long period of continental stability, which results in extensive peneplanation, meager terrigenous sediments and general marine deposits, extended epicontinental seas, and climatic and faunal uniformity.‡

11. The critical times which bring out continental structure are the

*A common connotation of the term *plastic*, namely, soft or softened, is explicitly excluded here. Plastic is used to describe the mode, not the ease, of motion.

†Bailey Willis: Research in China, vol. ii, Systematic Geology, chapter viii. Publication no. 54, Carnegie Institution of Washington, 1907.

‡The evidence of periodicity in earth movements and the effects of periodicity on climates and faunas are broadly and exhaustively set forth in the works of the author of the theory, T. C. Chamberlin. See Chicago Journal of Geology; Manual of Geology, Chamberlin and Salisbury, and Fundamental Problems of Geology, in year books and publications of the Carnegie Institution of Washington.

epochs of diastrophic activity. During the periods of inactivity the distinctions between heterogeneous elements become less obvious and may become obscured by extended peneplanation and marine transgression.

The critical epochs for North America occurred at intervals during the Proterozoic, distinguished only in the Lake Superior region; during the Silurian and Devonian; at the close of the Paleozoic; at the close of the Cretaceous, and on the Pacific coast during the Jurassic, late Tertiary, and Quaternary. Intervening among these were the Cambro-Ordovician, the lower Carboniferous, and the Cretaceous transgressions, which occurred during long periods of quiescence.

Positive Elements of North America

Examination of a geologic map of North America shows that there are several areas characterized by the presence at the surface of pre-Cambrian rocks which exhibit a schistose structure developed under great pressure, probably at considerable depth. This fact indicates elevation. The subjacent masses no doubt have at times subsided toward the earth's center along with the continent as a whole; they may have been depressed relatively to adjacent areas to some extent, but the algebraic sum of vertical movements has been upward, and has been positive as compared with other parts of the continent and the neighboring ocean bottoms. Whether they be regarded as horsts or as protrusions resulting from radial elongation, their movement is positive and they may fitly be called positive elements.

The geologic characteristics of a positive element are deep denudation, an absence of sediments of critical periods, and the corresponding prolonged duration of the sum of unconformities. Let us attempt to apply these criteria to an analysis of North America.

The Canadian shield, the protaxis of Dana, which is also called Laurentia, is at once the largest and most readily distinguished positive element of the continent. Dana described it as V-shaped, but the shallow Hudson bay, which forms the V, is but a small epicontinental sea submerging a part of the element. The true boundary may be traced along the Saint Lawrence valley into the deep of Baffins bay, and thence north of the Arctic archipelago (which is scarcely to be separated from Greenland), across the Arctic ocean and back to the mouth of the Mackenzie. Beneath the Cretaceous of western Canada the margin of the element lies hidden. It ranges past lake Winnipeg toward and around the isle Wisconsin, and thence follows the shore of the Paleozoic mediterranean east to the Adirondacks and the Saint Lawrence.

Throughout this vast area the Laurentian gneisses or the sediments into which they were intruded constitute the larger part of the surface. It was submerged probably beneath the general Cambro-Ordovician transgression and certainly to a great extent beneath the Siluro-Devonian seas which spread over Arctic lands (Siberia, northern Europe, and North America), while elsewhere in the globe there were notable phenomena of emergence; but these submergences and that of the Cretaceous were relatively brief and scarcely affect the grand total of unconformities, which ranges from Laurentian to the present. The net sum of relative depressions and elevations is positive by a large amount.

In the eastern part of the continent is the area of ancient schists and intrusives, whose relations have in the last few years been worked out chiefly by Keith.* They extend from the Pennsylvania line southward in a widening area, between the folded Paleozoics on the west and the metamorphosed Paleozoics on the east. Their surface sinks beneath the Mesozoic and Tertiary of the Atlantic coastal plain. The rôle of this area in Paleozoic history is well understood, in its broad outlines at least. From the beginning of the Ocoee (pre-Cambrian) on through the Cambrian it was an area of pronounced denudation. The Cambro-Ordovician sea probably swept over it entirely; but from late Ordovician time it stood for a long period relatively high with reference to the Paleozoic mediterranean on the west. At the close of the Paleozoic it became the scene of decided mountain growth, and throughout the succeeding eras it has either been stable or has been affected by a positive movement. The sum total of unconformities for this, which we may continue to call Appalachia, is much the same as for Laurentia, although the integers differ.

One of the most interesting speculations of American geology relates to the extent of Appalachia during the Paleozoic. On the basis of Paleozoic sediments, it may be credited with a wide expanse to the southeast over the area of the Blake plateau, but the suggestion is not capable of proof.

We may next turn to the Llano region of Texas. Here the pre-Cambrian rocks appear in consequence of relatively very recent upwarping, surrounded by Cambro-Ordovician, Carboniferous, and Cretaceous deposits. The three great transgressions which have affected the continent submerged the region. For other periods the record is one of non-sedimentation or erosion. The sum of unconformity and sedimentation appears to have a positive remainder, but the net elevation is by no means so large as in the case of Laurentia and Appalachia. The extent of this rather neutral element is indefinite. It is bounded by the gulf of Mexico

*Geological Atlas of the U. S., Roan Mountain and other folios.

on the southeast; on the north it probably extends to the folded zone of Paleozoics in Indian Territory;* on the west it appears to be separated by the zone of folding in central New Mexico from the similar elements in Colorado and Arizona.

Northeastward from the Llano element lies the Ozark, which is of a similar neutral, slightly positive, character. The sum of its unconformities comprises a pre-Cambrian period, the Siluro-Devonian in part, and the post-Paleozoic. The region lies midway between Isle Wisconsin and the Llano district, and, as was pointed out by Weller,† forms part of a zone which constituted a barrier to faunal migration during early Devonian time. Whether it be regarded as a continuous belt of land or as an archipelago among shallows capable of separating ocean currents, and consequently of keeping faunal provinces distinct, is not here important. The fact which bears on continental structure is that a zone of neutral character, with loci which appear as slightly positive elements, extends from Wisconsin to Texas.

An analysis of western North America with reference to positive and negative elements is complicated by the effects of Pacific thrust. I regard that vast ocean basin as the source of tangential pressure, which has stamped its bordering continents with a geologic history that is peculiar to the Pacific, in contrast to the sequences of events that are specially marked by movements that originated beneath the Atlantic or the Mediterranean-Himalayan zone.‡ The development of the Cordillera of North America, comprising all the mountain chains west of the Great plains and involving folding, intrusion, extrusion, and warping, I regard as a more or less direct effect of disturbances originating beneath the Pacific. These effects are superimposed upon the positive or negative movements of the continental elements and greatly obscure them. However, the analysis may be made, with appropriate reservations.

Colorado, Wyoming, and Arizona constitute an area in which the pre-Cambrian and Paleozoic sequences of sediments are comparatively incomplete. Except for the Grand Canyon section in the extreme southwest, the pre-Cambrian consists largely of gneisses and schists which resemble the oldest rocks of the Canadian protaxis, together with intensely metamorphosed sandstones and shales—that is, shore deposits. These rocks were deeply denuded before the invasion of the Upper Cambrian

*J. C. Branner: The former extension of the Appalachians across Mississippi, Louisiana, and Texas. Am. Jour. Sci., 4th series, vol. 4, 1897, p. 368.

†Chicago Jour. of Geol., vol. 3, 1895, p. 905.

‡Bailey Willis: Research in China, vol. ii, Systematic Geology. Publication no. 54, Carnegie Institution of Washington, 1907.

sea.* All the middle Paleozoic is wanting or is represented by slight and local sedimentation. The general Carboniferous transgression was followed by conditions of erosion and by deposition of continental or littoral formations during the Permo-Triassic and the late Mesozoic. Tertiary history has been largely one of elevation. Since the Carboniferous, however, the movements may be attributed in considerable degree to tangential compression rather than to positive or negative vertical adjustment. The sum of unconformities and the sum of sediments are not so different for this district of the Middle West as to stamp it in itself decidedly with a positive or negative character, but when compared with the definitely negative element which bounds it on the west, the Great Basin region, and considered with reference to the folds of the Laramide compression, it assumes a more distinctly positive character.

For the eastern boundary of this positive element, which we may designate as the Colorado, we may take the Front range from Wyoming south to Santa Fe. Thence the outline runs southwest to include most of Arizona, and, turning north, sweeps across southeastern California and Nevada toward Salt lake. The northern end includes the Belt mountains of Montana, east of Butte and south of Great Falls.

In western Nevada the King survey determined the existence of a Paleozoic landmass on the succession of Triassic strata unconformably on supposed Archean.† This particular line of evidence is invalidated by Loouderback's‡ determination of the intrusive nature of the supposed Archean into Triassic and possibly Jurassic sediments of the Humboldt range, for the descriptions of other occurrences resemble that which Louderback has revised. Nevertheless the character of pre-Cambrian and Paleozoic sediments in the Great Basin region, in western Montana and Idaho and in British Columbia, indicates that there was a western landmass, which prior to the granitic intrusions and metamorphism of the Mesozoic might have been distinguished by unconformities. Cambrian sediments in Nevada pass from a marine to a littoral phase from east to west, as observed by Walcott. Lindgren§ and Ransome‖ describe exposures of pre-Cambrian schists in central Idaho and the Cœur d'Alene district. Daly, in his reports on the international boundary survey,¶ has

*C. W. Cross on the pre-Cambrian of Colorado, in Bulletin on the Archean and Algonkian, by C. R. Van Hise and C. K. Leith, revised edition in press.

†Clarence King: Exploration of Fortieth Parallel, vol. 1, Systematic Geology, p. 247.

‡ G. D. Louderback: Basin range structure of the Humboldt region, Nevada. Bull. Geol. Soc. Am., vol. 15, 1904, pp. 289-346.

§ W. Lindgren: A geological reconnaissance across the Bitter Root range and Clearwater mountains, Idaho. Professional paper no. 27, U. S. Geol. Survey, 1904.

‖ Current manuscript report on Cœur d'Alene region.

¶ Summer reports, Canadian Geol. Survey, 1902-1905.

brought out the great thickness of pre-Cambrian clastics derived from a western land in British Columbia, and Dawson before him had described the Shuswap and Adams Lake series as having similar relations* to an Archean geanticline which occupied the site of the Gold ranges and extended as far north as latitude 57°. Although it is well known that the metamorphic schists of the western part of the Cordillera are in considerable part of Paleozoic age and are not lightly to be reckoned as ancient pre-Cambrian gneisses whose presence at the surface would indicate pronounced elevation, nevertheless the sediments derived from a western land and deposited in pre-Paleozoic or Paleozoic seas prove the existence of a positive continental element in the Pacific region. Traced southward through British Columbia into western Montana, the old land area is lost under the post-Paleozoic intrusives and Tertiary volcanics of Idaho and Oregon. South of the Snake River flows it appears to have occupied western Nevada and northern California, including possibly the Klamath Mountain region.

Proceeding northwestward beyond British Columbia, we find the Yukon plateau, which according to Brooks is a region of deeply denuded early Paleozoic or older rocks, flanked both north and south by folded Paleozoic and Mesozoic strata. The central area may represent a positive element, the backbone of Alaska, compressed between the thrusts from the Pacific and Arctic basins.

In Mexico and Central America there are areas of so-called Archean rocks which might be interpreted as evidences of centers of elevation; but the relations of unconformity are with rocks as late as the Mesozoic where they are determined, and there is nothing to exclude the hypothesis that the schists are metamorphosed Paleozoics, whereas the general descriptions of the rocks by Ordonez† and Sapper‡ invite comparison with the altered Paleozoics of the Great basin and California. It seems very doubtful if there be a positive continental element in the peninsula region south of Arizona.

To sum up the enumeration of the positive continental elements, we may name and characterize them as follows:

Laurentia, the protaxis of Dana, the region of exposure of the most ancient rocks, over which the sum of unconformities is apparently equal to all post-Laurentian time and is to be reduced only by the epochs of general submergence of Arctic lands.

* G. M. Dawson: Geological record of the Rocky Mountain region in Canada. Bull. Geol. Soc. Am., vol. 12, 1901, p. 84.

† L'archaique du Canon de Tomellin, par Ezeq. Ordonez, Guide Geologique de Mexique, X Int. Congres, Mexico.

‡ Uber Gebirgsbau und Boden des nordlichen Mittelamerika, C. Sapper, Peterm. Mitt. Erganzungsband xxvii, no. 127.

Appalachia, the eastern element, which was a conspicuous land area during the Paleozoic and is characterized by a sum of unconformities nearly, if not quite, equal to that of Laurentia. Its eastern portion, which was presumably more extensive than the area now bounded by the Atlantic, has been more or less submerged since the early Mesozoic.

Llano and Ozarkia, the more conspicuous points in a zone where the balance of unconformities and sediments is nearly even and their algebraic sum may be roughly estimated as zero, with perhaps a plus correction.

The Rocky Mountain element, comprising Wyoming, Colorado, and Arizona, which is distinguishable by a sum of unconformities that gives it a positive character in spite of frequent submergence and is more clearly recognized as a recurrent landmass when compared with the adjacent negative region of the Great basin.

A Pacific element, occupying Nevada and a zone extending thence northward to latitude 57° in British Columbia and westward to an unknown distance, determined chiefly on the pre-Cambrian and Paleozoic sediments derived from it.

The Yukon element, an element comprising the ancient rocks of the Yukon plateau, which apparently has been the source of Paleozoic and Mesozoic sediments of the Pacific and Arctic littorals.

Possibly, but not probably, an isthmian element or elements represented by the ancient schists of Mexico and Guatemala.

Negative Elements of North America

By contrast with the positive elements of the continent which are recognized by absence of sediments and preponderance of unconformities, the negative elements are distinguished by the sediments which bury them. The significant strata are practically limited to the Paleozoic and Mesozoic, as pre-Paleozoic terranes, with the exception of the Huronian, the Belt, and the Ocoee, are too limited in occurrence to give tangible evidence, and as the possible effects of post-Mesozoic isostatic adjustment are profoundly modified by the compression and intrusion that mark the Cordilleran orogenic activity.

Through his studies of the Cambrian, Walcott* first distinguished the eastern and western troughs which are the loci of the principal negative elements, the Appalachian trough and that of Nevada and British Columbia.

* C. D. Walcott: The North American continent during Cambrian time. Twelfth Ann. Rept. U. S. Geol. Survey, pt. 1, pp. 529-561.

In the Appalachian trough opportunity for maximum sedimentation during the Paleozoic was afforded by the profound subsidence of an area in New York, Pennsylvania, Virginia, and Ohio. At Mauch Chunk the total thickness is approximately 30,000 feet. The Devonian subsidence alone was 10,000 feet, and the area of the sunken element is well indicated by the mussel-shaped form which the Hamilton black shale had assumed by the close of Devonian time.* This element presents a striking contrast with Appalachia, the positive mass which bounds it on the east. The maximum vertical displacement of the negative with reference to the positive can scarcely have been less than 40,000 feet during the Paleozoic era. Let us call this sunken area the northern Appalachian negative element.

A second area of notable subsidence occupies the southern end of the Appalachian trough. It developed during the Ocoee epoch (late pre-Cambrian or Cambrian) and continued throughout the Paleozoic to be a region of more or less subsidence and deposition. The total thickness of strata, including the Ocoee, is probably 20,000 feet, and the displacement with reference to Appalachia was probably not less than 25,000 feet. The area comprises part of western North Carolina, northern Georgia and Alabama, and eastern Tennessee. We may call this negative element the southern Appalachian.

The northern and southern Appalachian negative elements were apparently distinct, although the zone of Paleozoic sediments and Appalachian folding connects them; but in southern Virginia there are unconformities in the sedimentary series which give the district a distinct character with a less decided negative tendency.

The Rocky Mountain trough, as Walcott called it, occupies the Great Basin region in the United States and the ranges in British Columbia between the Great plains and the Columbia river, together with their extensions southward into Idaho. Between the Great basin of Nevada and southern Idaho, there lies in central Idaho and western Montana a district in which the great thicknesses of pre-Paleozoic and Paleozoic sediments appear to be wanting. The trough is thus apparently divided into a southern and a northern part.

Over the Great Basin element, as we may call it, Paleozoic sediments accumulated to a thickness of 32,000 feet, according to King.† The Eureka section comprises 30,000 feet.‡ In contrast with these great

* Bailey Willis: Paleozoic Appalachia. Maryland Geological Survey Reports, vol. 4, pp. 61-62, pl. iv.

† Clarence King: Geological Survey of the Fortieth Parallel, vol. 1, Systematic Geology, p. 246.

‡ Arnold Hague: Geology of the Eureka district. U. S. Geol. Survey, Monograph xx, p. 208.

thicknesses we may place that of 5,000, determined by Walcott for the Kanab section, Arizona, which lies on a positive element. The condition which determined the accumulation of 30,000 feet of strata in the Great Basin region was, I take it, the subsidence of that area between the Colorado element on the east and the Pacific element on the west. This movement was a decidedly negative one.

In northern Idaho, western Montana, and British Columbia, there is a thickness of 37,000 feet of late Proterozoic (Algonkian) strata,* and to this we must add the Paleozoic, which comprises† at least 17,000 feet above the base of the Castle Mountain group.

This region of profound subsidence lies between the Pacific land, from which the bulk of the sediments was derived, and Laurentia. In comparison with them its negative character stands out distinctly.

The negative elements of the central portion of the continent present very diverse aspects.

Between Missouri and Colorado the region of the Great plains is the surface of a comparatively thick mass of Paleozoic and Mesozoic sediments. Along its southern margin the Paleozoic measures 18,000 to 23,000 feet in thickness,‡ including the Middle Cambrian and the Carboniferous. The strata rest on pre-Cambrian granites, which appear to constitute the northern limit of the Llano positive element. The extent of the Great Plains element northward from Indian Territory and Oklahoma is not readily defined. The Paleozoic sections of the Colorado Front, the Black Hills, and the Bighorn§ range from 1,000 to 3,000 feet only and represent the sediments deposited on the margin of the Colorado positive element. Adding the Mesozoic, we get a total of 8,000 feet, much of which falls in the upper Cretaceous and therefore in a period of tangential pressure, when subsidence and elevation can not be attributed without question to isostatic vertical adjustment. Nevertheless it appears probable that a trough separated Colorado from Ozarkia and Laurentia during the Paleozoic and Mesozoic and connected with the negative element of British Columbia.

East of the Ozarkia-Isle Wisconsin zone the coal basin of Illinois presents an area of moderate depression which is bounded on the east by the Cincinnati-Nashville axis. In Michigan is a similar basin. I regard

* C. D. Walcott: Algonkian formations of northwestern Montana. Bull. Geol. Soc. Am., vol. 17, 1906, pp. 1-29.

† R. G. McConnell: Report on the geological structure of a portion of the Rocky mountains. Canada Geol. and Nat. Hist. Survey Rept., 1886, pt. 2, 1887.

‡ J. A. Taff: Preliminary report on the geology of the Arbuckle and Wichita mountains. Professional paper no. 31, U. S. Geol. Survey, 1904.

§ N. H. Darton: Geology and underground waters of the Great plains. Professional paper no. 32, U. S. Geol. Survey, pl. xii, p. 42.

the fact of deeper subsidence in both of these basins as evidence of a relatively negative character.

Two negative elements remain—the one the youngest, the other the oldest recognized. The Mississippi embayment was a region of subsidence during the Tertiary and Cretaceous. Its behavior during earlier periods is indeterminate, but the migration of faunas between North and South America appears to require such a waterway along a favoring coastline as would be provided by a connection southwestward via the Mississippi embayment. We can never know positively, but it is a reasonable presumption, that the region formerly had the character which it now possesses and which causes it to stand low.

The oldest region of which we are able to decipher the stratigraphic history is that about lake Superior. The thickness of Lower and Middle Huronian sediments is given at 6,000 to 18,000 feet, and that of the Upper Huronian as 14,000 feet.* The sediments of the Keweenawan measure 15,000 feet, and although this may not be the true thickness of the beds they nevertheless correspond to a notable subsidence. The sum of these measures shows that the region was one which sank with reference to adjacent areas (presumably Laurentia), and thus during the early ages of continental history exhibited a negative character. The process of intimate folding to which the strata were subjected welded them to the positive element in such manner that they have since shared its elevatory movements; yet the district may still be affected negatively, if we may regard the syncline in the Keweenawan beds and the existing depression as effects of vertical movement due to isostacy.

The negative elements of the continent which have been described may be briefly enumerated as follows: The northern Appalachian (New York to Virginia), the southern Appalachian (North Carolina, Georgia, Alabama, and east Tennessee), the southern Rocky Mountain (comprising the Great basin), the northern Rocky Mountain (located in British Columbia and Idaho), the Great Plains (best developed in Indian Territory and Oklahoma, but probably continued northward to the northern Rocky Mountain trough), the Illinois and Michigan, the Mississippi, and the Lake Superior negative elements.

Theoretical Considerations

The masses which have been distinguished as positive and negative elements appear to stand in contrast according to the predominance of unconformities or deposits. I regard them as distinct independently of any

* Chamberlin and Salisbury: Manual of Geology, 1st edition, vol. 2, pp. 176 and 184.

hypothesis of the conditions to which they owe their positive or negative character. We may, however, frame a hypothesis in accordance with Dutton's original statement of isostacy,* which runs:

"If the earth were composed of homogeneous matter its normal figure of equilibrium without strain would be a true spheroid of revolution; but if heterogeneous, if some parts were denser or lighter than others, its normal figure would no longer be spheroidal. Where the lighter matter was accumulated there would be a tendency to bulge, and where the denser matter existed there would be a tendency to flatten or depress the surface. For this condition of equilibrium of figure, to which gravitation tends to reduce a planetary body, irrespective of whether it be homogeneous or not, I propose the name *isostacy.*"

In his explanations, Dutton laid emphasis on effects of erosion to a degree which has led to a general oversight of the fact that his primary conception dealt with an earth composed of lighter and denser bodies, but that original idea was clearly his. The misleading discussions of the efficacy of erosion and sedimentation to produce isostatic adjustment should be set aside, that cause being clearly subsidiary and self-destructive where effective at all. Through investigations of the deflection of the plumbline observed in the primary triangulation of the United States, Hayford reaches the conclusion that for the United States and adjacent areas it may be assumed, with a close approximation to the truth, that the earth is in the condition called isostacy.† He uses the term in the sense quoted above from Dutton.

Hecker's determinations in the Atlantic and Pacific basins‡ suffice to show that the intensity of gravity is what it would be on a lithospheroid of the radius of sealevel; in other words, there is an excess of material beneath the ocean bottoms very nearly, if not exactly, equivalent to the depth of the ocean at the point of observation. There are some exceptional results, which do not agree with the rule, but as a whole the observations give very strong support to the theory of the existence of an isostatic balance between the suboceanic and the subcontinental masses.

In applying the hypothesis of density differences to the distinct parts of the continent, we tread on speculative ground. A firm foundation

* C. E. Dutton: On some greater problems of physical geology. Bull. Phil. Soc. Washington, vol. xi, 1889.

† O. H. Tittmann and J. F. Hayford: Geodetic operations in the United States, 1903-'06. A report to the fifteenth general conference of the International Geodetic Association. Washington, 1906.

‡ Bericht über die Schwerkrafts messungen aufdem Meere, O. Hecker. Nature, June, 1904, p. 104; Sitzungsbericht, Ak. der Wissensch. zu Berliin, Febr., 1902; Veroffentlichung des k. preuss. geodät Instituts, Neue Folge no. 11, Berlin, 1903; Bericht zum xv Intern. geodät Konferenz zu Budapest, 1906.

can be laid only through observations of the intensity of gravity which actually exists in different sections and consideration of the qualifying effects of tangential pressure and igneous activity. Nevertheless the speculation is worthy of being entertained. The observed vertical displacements of negative elements with reference to positive elements are equal to or of the same order of magnitude as oceanic depths; the masses involved are some of them of subcontinental dimensions; the rate of subsidence or elevation has been gradual in general, though periodically accelerated, and for a given element the movement has been in the same sense positive or negative during long geologic periods.

Hence I postulate as a basis of a theory of continental structure that the continent consists of elements which differ in density and which have been controlled in certain movements of elevation or subsidence by the differences of density existing among them.

Effects of tangential Pressure

In the conclusion just stated, the effects of isostatic adjustment are qualified by restriction to *certain* movements of elevation or subsidence. Certain other movements of elevation, and possibly also of depression, are attributable to tangential pressure. Further, it is thought probable that the two effective conditions (deficient density and horizontal thrust) may combine to cause a given elevation. And, finally, it is recognized that as a result of tangential pressure a region which had previously possessed the character of a negative element and suffered depression may become a region liable to uplift.

These relations may best be illustrated by reference to the history of Appalachia and the adjacent negative elements on the west. The pre-Cambrian movements of Appalachia, so far as we know them, resulted in profound erosion and were movements attributable to isostatic elevation. Whether the negative elements were then effectively differentiated or not, we do not know. During the Paleozoic the positive movements continued to be of an isostatic type and there were negative displacements of the same kind. Only in the Devonian was there an exceptionally energetic orogenic effect which might be attributed to tangential thrust, and, restricted as this was to a district east of Pennsylvania and New York, the uplift may have belonged to the New England province, which appears to have had a distinct dynamic history, as will appear in the further discussion.

The Appalachian revolution greatly modified the previously existing conditions. Appalachia, the positive element, apparently lost a consider-

able eastern section, which sank to the depth of the Atlantic basin, and the strata that had accumulated beyond its western shore in the mediterranean sea were folded up to a notable mountain range which stood upon the negative elements. Subsequently the whole eastern portion of North America was reduced to a peneplain, and in relatively modern times has suffered that broad doming with subordinate corrugation which constitutes the existing Appalachian mountains. The early effects that we recognize as the Appalachian revolution and those which have followed may be credited, I think, to the tangential thrust which is exerted by the sub-Atlantic mass on the elements of the Appalachian province, both positive and negative, whereas the conditions which prevailed prior to the Appalachian revolution were peculiar to continental elements that were not under dominant tangential stress.

The distinction might be explained by the periodicity of tangential movement, if we could assume that no notable thrust had been exerted by the sub-Atlantic mass before the close of the Paleozoic; but, while it is true that there were long intervals of inactivity, there is, for instance, the Taconic disturbance, which affected New England and not Pennsylvania. Special developments of mechanical relations appear to afford a better explanation of this and other obscure changes of condition. Thus, in explanation of the supposed effectiveness of a sub-Atlantic thrust upon the eastern United States at the present time, let us consider the larger movements of the Appalachian revolution and their mechanical effects. It is well established that the folding of the Paleozoic strata in the Appalachian zone corresponds to a narrowing of the zone by 35 miles or more—that is, the Blue ridge approached the Cumberland plateau from a distance of 100 miles to within 65 miles. The general effect may best be described as a composite overthrust from southeast toward northwest. Keith's recent investigations* show that overthrusts of equal or greater displacement traverse the gneisses of the Smoky mountains. Hence it is a moderate statement to say that during the Appalachian revolution that portion of the continent southeast of the Cumberland Plateau rim moved northwestward at least 50 miles. If this movement be conceived as affecting a superficial film, the mechanical effects need not be supposed to modify the continental structure, but the phenomena, such as the dip of the thrust planes, for instance, indicate a deeper origin, and it appears reasonable to regard this displacement as one which involves the subcontinental and suboceanic masses down to the

* Arthur Keith: Folded faults of the southern Appalachians. Compte Rendu de la ix session du Congres Int. a Vienne, vol. 2, 1903, p. 541; also Atlas U. S. Geol. Survey, Roan Mountain and other folios.

limit of effective plastic flow, which should correspond with the depth of the zone of isostatic adjustment, 71 to 100 miles, as stated by Hayford in the article already cited. The mechanical effects of the pressure, as we observe them in masses which were not very deeply buried when displaced, are seen in numerous shearing planes on which, under appropriate stress, the masses rose as on an inclined plane. The parallel mechanical effects in the depths beyond our observation, I conceive to be shearing planes or their equivalents, planes of incipient displacement, on which any part of the mass moves northwestward and upward when adequate pressure is exerted from the sub-Atlantic region. Such a pressure is, I postulate, now exerted, and the combined effect of very deep-seated displacements is seen in the present doming of the Cretaceous peneplain. Prior to the Appalachian revolution this condition did not, however, exist in the subcontinental section which is now affected.

The preceding discussion of shearing planes suggests why the surface of the eastern United States is now elevated and, per contra, why the region was not similarly affected before the Appalachian revolution. There is another line of reasoning along which the same conclusion may be reached. The ancient eastern coastal region of Appalachia, from the latitude of New York to the Bahamas, lies beneath the Atlantic ocean beyond our ken; but its homologue, the New England-New Brunswick-Newfoundland zone, the eastern coast belt of Laurentia, is well known. The latter has been intensely folded by Atlantic pressure, which was, however, absorbed in the process and was not effective in the adjacent districts of Laurentia. By analogy we may reason that Atlantic pressures were taken up by an eastern coastal zone of Appalachia during the Proterozoic and Paleozoic eras and the region of the mediterranean province remained free from tangential stress for that reason.

The effects of pressure of the sub-Pacific mass upon North America are less well known than those of the Atlantic and they appear to be more complex. The Great basin and eastern British Columbia lie within the Pacific positive element, which separates them from the Pacific, precisely as the Appalachian folded zone lies within Appalachia. In neither case is the folded zone the immediate margin of the continent. The analogy of position requires a similar mechanical effect on the Pacific side as on the Atlantic, and one who accepts the evidence of the displacement of Appalachia can not well escape the inference that the Pacific positive element was likewise driven in during the movements that led to the folding of the Paleozoic of the Rocky Mountain trough.

At that date the eastern limit of the folded zone, which we may take as marking the effective radius of Pacific thrust, was the Wasatch dis-

trict on the Fortieth Parallel section. It does not follow, however, that that limit was never passed by movements originating in the distant but vast suboceanic mass. The folding which occurred during the late Cretaceous and Eocene throughout the Rocky Mountain province, even as far east as the Front range of Colorado, is to be attributed either to Pacific thrust or to pressure exerted from the region of the Great plains. The latter involves the spreading of the negative element that lies beneath the plains, at least according to the hypothesis entertained, that tangential movements in the earth's crust are due to displacement of the lighter elements by lateral spread of the denser masses. It would seem, however, that the relatively light and small negative element beneath the Great plains is a very inadequate source of tangential thrust as compared with the comparatively dense and enormous mass beneath the Pacific. As already stated, I regard the latter as the source of the orogenic activity which has produced the Cordillera from Alaska to cape Horn, and this conclusion necessarily includes the section in Colorado.

Throughout the Cordillera the effects of tangential thrust in modifying the isostatic relations which might otherwise exist among positive and negative elements appear to be obvious, and I will not dwell upon them.

We may next turn to the zone of folding which crosses Arkansas and Indian Territory and is represented by the novaculite area and the Arbuckle-Wichita mountains. The structures are described by Branner,* Griswold,† and Taff,‡ who are agreed that the Paleozoic land area lay to the south. Griswold states (page 213) that the direction of pressure was from the south. Thus, if the gulf of Mexico and northern Mexico be regarded as the site of a negative element from which the tangential thrust was exerted, this zone of folding occupies a position within the Llano positive element which is homologous with that of the Appalachian or that of the Great Basin zones.

The effect of tangential thrust in transforming the deep Paleozoic basin of the southern Great plains into an area liable to uplift is entirely similar to the change in the tendencies of the Appalachian mediterranean.

In the preceding paragraphs the Atlantic, Pacific, and Mexican basins are regarded as the sources of the tangential pressures which have affected the intervening continent. The Arctic remains to be consid-

* Ibid., Am. Jour. Sci., 4th series, vol. 4, 1897.

† Arkansas Geological Survey Ann. Rept., 1890, Novaculites, by L. S. Griswold, 1892.

‡ J. A. Taff: Preliminary report on the geology of the Arbuckle and Wichita mountains. Professional paper no. 31, U. S. Geological Survey, 1904.

ered. There is a folded zone in Grantland extending from Lincoln sea to the Sverdrup islands and involving Triassic and older rocks.* Beyond the fact that it is there, we know but little about it. In Alaska the mountains north of the Yukon plateau are composed of moderately folded Paleozoic and Mesozoic sediments,† the structure and stratigraphy of which are but imperfectly known.

But though there is yet much to learn of the structure of Arctic North America, we may nevertheless compare it with northern Siberia as a region in which tangential pressure has been but feebly exerted, at least since the beginning of the Paleozoic. The Arctic ocean being but a relatively small and not exceedingly deep basin, this result is consistent with the hypothesis that the pressures were exerted from it upon the adjoining positive elements.

In the compressed folds of the iron ranges, the Lake Superior region offers a problem of tangential pressure which is rendered obscure by antiquity and isolation. If we consider it by itself, we may say that during the Huronian period the zone between Isle Wisconsin and Laurentia was alternately the scene of deposition, folding, and erosion until three thick, distinct series had accumulated. These phenomena were accompanied and followed by intrusive and extrusive igneous activity. The region has since then been very deeply eroded and remnants of the deepest troughs alone contain the sediments. The trend of the folds shows the dominant north-south direction of pressure; but, so far as the local conditions go, there is no evidence as to whether the applied thrust was exerted toward the south or toward the north.

There is a broader view of the northern regions, which gives the events of Huronian time a setting in a worldwide phenomenon: the grouping of vast areas of highly schistose, so-called Archean rocks about the Arctic. The Canadian protaxis, Siberia, Russia, and Greenland, constitute masses of great magnitude, which are composed chiefly of very ancient gneisses and schists, that had been forced from great depths to the surface before the Proterozoic era approached its end. Their rising was in part determined probably by isostatic adjustment, but the condition of the rocks shows that in the depths from which they have come they were subjected to intense tangential stress. That this stress was exerted in a general way from south toward the north we may infer from the following considerations: We have seen that there is reason to conclude that those por-

* Sverdrup: The New Land.

† A reconnaissance in northern Alaska, across the Rocky mountains, by F. C. Schrader. Professional paper no. 20, U. S. Geological Survey, 1904. Geography and geology of Alaska, by A. H. Brooks. Professional paper no. 45, U. S. Geological Survey, 1906, pl. xxvii.

tions of North America outside the Canadian protaxis have been pushed northwestward, northward, and northeastward toward it, until the continent may be said to consist of that great nucleus with a group of smaller bodies arranged about it. So with Asia, though in more striking manner. Suess has distinguished the Urscheital in central and northern Siberia and compared the structure of the continent to an arrangement of garlands pendent from it.* A study of the continental history of Asia according to our present information shows that the northern landmass gained in area by additions on the south and east through the northwestward and northward movements of smaller positive elements.†

The general structure of Europe may be roughly expressed by the statement that its southern and western elements have been pushed northward and eastward toward the Russian nucleus.

If now we consider the distribution of land and water throughout the globe, we find a southern oceanic hemisphere and a northern continental hemisphere.‡ According to the evidences of isostatic equilibrium, this arrangement corresponds to that of lighter and denser elements; and according to the theory of suboceanic spread here entertained, the general northward movement of continental elements and the effects of tangential pressure exhibited by the ancient gneisses and schists of the great northern nuclei are due to the stress exerted by the heavier suboceanic mass of the water hemisphere.

Considering the immense embayments of the northern Pacific and Atlantic oceans among the continents, it is obvious that no symmetrical relation of stresses can exist; yet, in view of the vast eras during which the conditions have endured, there can be no doubt that the stresses of which the Arctic is approximately the center have long since tended toward an equilibrium. Hence the stability of northern lands.

Zones of Intrusion

In discussing the zones of intrusion and extrusion of North America, the immediate purpose is to enumerate those which appear to have relations to the positive and negative elements that have been distinguished.

It is well known that intrusives constitute a very large proportion of the rocks of Laurentia, Appalachia, and similar areas. The fact is interpreted by Van Hise§ and also by Chamberlin‖ as evidence that the

* Das Antlitz der Erde, vol. 3, chap. 3.

† Bailey Willis: Research in China, vol. 2, Systematic Geology. Publication no. 54, Carnegie Institution of Washington, 1907.

‡ Stieler's Atlas, 1905, Karte 3, Land und Wasser Halbkugel.

§ C. R. Van Hise: A treatise on metamorphism, p. 707.

‖ T. C. Chamberlin and R. D. Salisbury: Manual of geology, 1st edition, vol. 2, pp. 130-131.

associated rocks were formerly buried to a depth at which intrusive masses are more generally present than they are at the surface, and in relation to our subject, it is merely one of the evidences of decided elevation and pronounced erosion of the positive elements.

There are, however, zones in which igneous intrusions are peculiarly voluminous in rocks that never were so deeply buried. Some of these occur between a positive and a negative element or between two negative elements; others, as the Cordillera, are widely distributed without apparent order.

The New England-New Brunswick-Newfoundland zone, which in fact extends from Philadelphia to Saint Johns, Newfoundland, is one of the first kind. It lies between Laurentia, to which we must reckon the Adirondacks and Highlands, and the Atlantic, *i. e.*, between two of the largest elements we can distinguish, one of which is very decidedly positive and the other pronouncedly negative. The dynamic activities in this zone have repeatedly been marked by igneous intrusion and extrusion from early Proterozoic time to the Triassic. In explanation of this condition we may point out that the zone between the sinking Atlantic element and rising Laurentia was a zone of displacements, in which temperature and pressure must vary notably, and consequently conditions would arise favorable to the formation of molten masses.*

These conditions distinguish the New England province from the Southern Appalachian, where the absence of vulcanism, except in the late Proterozoic and Triassic epochs, is a conspicuous and unexplained fact.

In the Lake Superior region volcanic and plutonic activity was frequent on a very large scale until the close of the Keweenawan, when it ceased apparently forever. During the periods of activity the region had a negative tendency and lay adjacent to the Laurentian and Wisconsin elements. When the vulcanism was finally extinguished the negative element had become welded to the positive in consequence of tangential thrust, and it has since moved with them.

Throughout the great western Cordillera intrusive and extrusive rocks are so widely distributed that it is apparent no one simple condition of continental structure controlled their appearance. The widespread and obvious igneous masses have, however, been erupted since the Triassic—that is, since the continent acquired a certain unity and since the development of those hypothetical deep-seated shear zones which seem essential to the eastward movement indicated by folding. With these relations in mind, we may suggest that the Mesozoic and younger intrusions bear

* P. G. Tait: Heat, 1884, p. 123.

a relation to displacements of the united western continent with reference to the Pacific, and, further, that the mechanical structures of the subterrane have been effective in directing the movement of molten masses, even to great distances from the margin of the oceanic basin. Pre-Mesozoic conditions of intrusion, when better known, may shed more light on the relations of particular zones to continental elements. To a great extent they still evade analysis, but not entirely.

The general structure of Alaska has been briefly described as consisting of a narrow positive element, the Yukon plateau, and two zones of folding, the one on the margin of the North Pacific, the other on the edge of the Arctic negative element. The southern is a region of intense folding, the northern a belt of moderate compression, as might be expected from the relative magnitudes of the two elements. Since an early Paleozoic date, at least, a similar relation has existed between intrusive activities on the southern and northern sides of the peninsula. The distribution in time and place can be made out from the correlation table and general comments by Brooks.* It appears that the zone between the rising Yukon element and the sinking Pacific basin was in Devonian, Carboniferous, and Mesozoic times the scene of pronounced intrusion and extrusion.

Attention is called particularly to the Mesozoic intrusion of the great granodiorite bathylith which extends from Alaska to southern British Columbia and which ranks among the stupendous events of Cordilleran history. The relation of the mass to the ancient elements of the continent and to their marginal zone after they became united is apparent.

I conclude that the older Cordilleran intrusions in some degree exhibit relations to the separate positive and negative elements, but that the late Mesozoic and Tertiary eruptions are phenomena which can be explained on this theory only by contrasting the united mass of the western North America with the suboceanic mass beneath the Pacific.

The Mexican-Isthmian extension of the continent may possibly be homologous with Alaska, may consist of a positive nucleus, which is compressed between the Pacific and Gulf negative elements. If so, the old land area extended from Guatemala through Oaxaca and along the Pacific coast toward Durango; but I have already referred to the descriptions by Ordonez and Sapper, which lead rather to the conclusion that the pre-Cretaceous rocks are chiefly metamorphosed Paleozoics and intrusives. The great unconformity of the region, so far as we yet know, is that at the base of the Cretaceous. The metamorphosed rocks and in-

* A. H. Brooks: Geography and geology of Alaska. Professional paper no. 45, U. S. Geol. Survey, 1906, pp. 206 and 250.

trusives were somewhat eroded and then sank under the Cretaceous sea till more than 20,000 feet of limestone had accumulated. This thickness of organic sediment marks a Caribbean deep and the flow of a warm life-bearing ocean current across it. The subsidence to so great a depth after considerable erosion is peculiar. No well defined positive element is known to have been equally depressed since the late pre-Cambrian, at least.

Fixing attention for the moment on the Isthmian region, we may recognize that it is with reference to the Caribbean and Pacific deeps merely a narrow ridge, comparable in position with the Windward islands or the ridges between the several deeps of the West Indian archipelago, including those which are submerged. These are but the rims of great deeps, and if the latter be considered as corresponding to negative elements of excessive density, there is scarcely space between them for a notable mass of deficient density equivalent to continental lightness. Nevertheless any two adjacent deeps are plainly not one, but are separate individuals lying in a mass whose density, though apparently less than theirs, is probably greater than that of the positive continental elements.

If we may assume that each of the heaviest elements adjusts itself individually to the stresses to which it may be subjected (whether they be directly those of gravitation or the indirect effects of that force expressed in tangential stress), then the zone between two such elements is liable to be one of excessive pressure, rising temperature, yielding, elevation, relief, and melting; consequently a zone of intrusive and extrusive igneous rocks, as well as one of highly metamorphosed sediments. Such a zone, it seems to me, is that of the Windward islands, that of the Isthmus at least as far north as Guatemala, and also that of the Aleutian islands, Alaska. In the absence of any well defined positive element, characterized by great unconformities and defined by marginal folded sediments, I am inclined to regard most of Mexico as of the same type—a region whose isostatic tendencies were negative, as compared with the positive element of Arizona, but which has lost its isostatic balance and been overelevated in consequence of displacement by the denser bodies adjacent to it.

Summary

This article contains:

(*a*) A statement of hypothesis according to which a continent is composed of lighter and heavier bodies, whose relative vertical movements have to some extent been in obedience to isostatic adjustment. The differences of density are postulated as original differences, not accounted

for. which were, however, more or less effective in producing vertical displacements so long as the mechanical relations of the masses were not materially affected by tangential pressure.

(*b*) The criteria of unconformity and sedimentation are applied to an analysis of North America to distinguish the lighter elements which have often been land areas from the heavier elements which have more often been submerged. The elements thus recognized are enumerated and described as positive (lighter) and negative (denser) elements.

(*c*) The effects of tangential pressure are considered in a large way, and it is recognized that North America has been narrowed by compression from the Atlantic and Pacific sides. The pressures are attributed to deep-seated *suboceanic spread*, and their effects in modifying the relations of elevation or depression due originally to isostatic adjustment are discussed.

(*d*) Displacements of lighter and denser masses are regarded as one cause of variations of temperature and pressure to which we may ascribe the formation of igneous masses, and zones on which such masses border are discussed as favorable places for the development of intrusive and extrusive bodies. The courses taken by igneous bodies rising toward the surface are in some degree directed by the thrust planes set up in consequence of tangential movements, and the distribution of bathyliths and volcanics is accordingly modified, as in the Cordillera.

The resultant conclusion is that the dominant geologic phenomena of the history of North America are in accord with the view that the continent consists of heterogeneous elements, which primarily exhibited more or less simple isostatic relations, but which in consequence of tangential pressure and igneous intrusion are no longer in close isostatic adjustment among themselves, although the composite continental plateau as a whole apparently is in equilibrium with the adjacent ocean beds.

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GLACIAL EROSION IN THE NORTHFIORD*

BY MARK JEFFERSON

(Presented by title before the Society December 28, 1906)

CONTENTS

INTRODUCTION

I went to Norway in the summer of 1904 to familiarize myself with the work in modifying topographic forms that the largest ice sheet in Europe is doing. This is the Jostedalsbrae, the word *brae* meaning any permanent sheet of snow or ice, moving or stagnant, level or inclined. It has an area of 360 square miles, and lies between the heads of Northfiord and Sognefiord, distant from the Atlantic 60 and 90 miles respectively by those fiords, at an elevation of about one mile above them. I visited this ice sheet by the Northfiord because the Olden and Loen lakes at its

* Manuscript received by the Secretary of the Society from the censor September 19, 1907.

head lie close under the edge of the ice, though themselves only 150 feet above the sea, amid scenery that Richter has called the most characteristic in Norway.

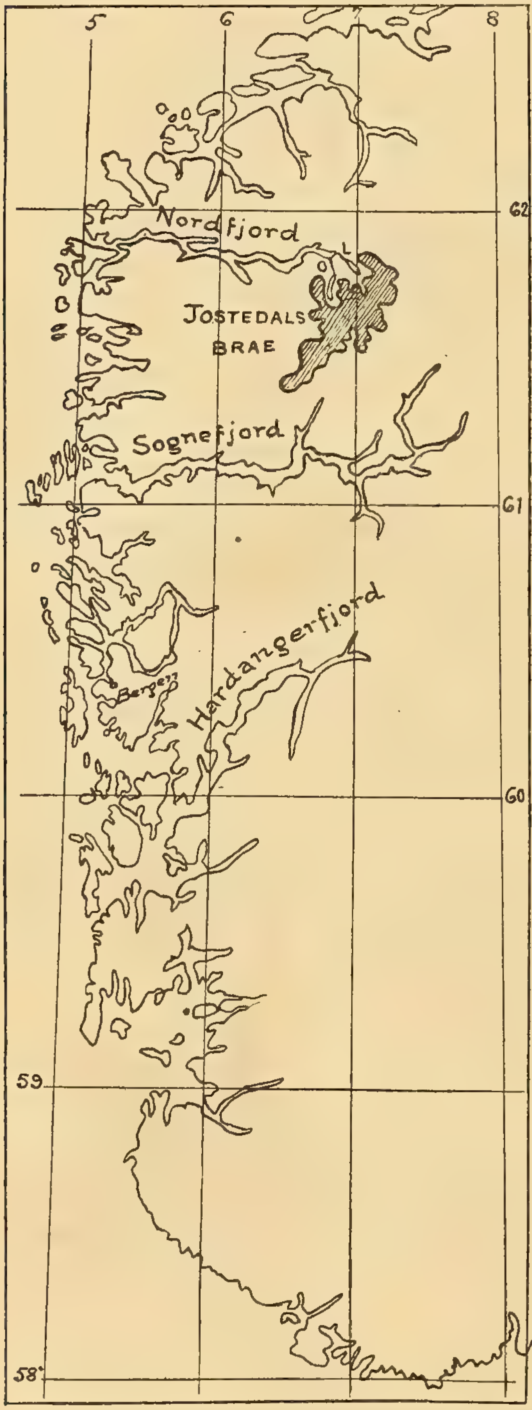

FIGURE 1.—*West Norway and the Three great Fiords.*

I did not find the Northfiord the steep-sided canyon that I expected. The country about it is high—3,000, 4,000, and 5,000 feet above the water. The water is deep, in some places 1,800 feet, and the width is hardly so great as 3 miles anywhere in the 60 miles of length. The side slopes, however, are rarely more than 30 degrees. The appearance is of mountain rather than of canyon scenery. This is typically shown by figure 2, plate 40, looking out into the fiord from its head at Loen. The same scenery characterizes the other two great fiords, Sogne and Hardanger.

The Northfiord has no walls of rocks, rising steeply, smoothed and striated by the ancient glaciers. Cliffs are seen, but they are not characteristic. At the head of the fiord, however, its valley forks and leads back some 15 miles along the Olden and Loen lakes in gorges of astonishing depth and steepness of rocky wall. Here slopes of 70 and 80 degrees are frequent under the valley shoulder. The cross-section here excels that of the Colorado canyon in narrowness and depth. The ice accumulations of the Jostedal

plateau are disposed of by melting and plunging over the cliffs in numerous streams, by falling bodily over the cliffs at more than a hundred points—the so-called glaciers of the second class—and in more than twenty great tongues of ice that cascade into the chasms at the fiord head. Two of these enter each of the lakes named above.

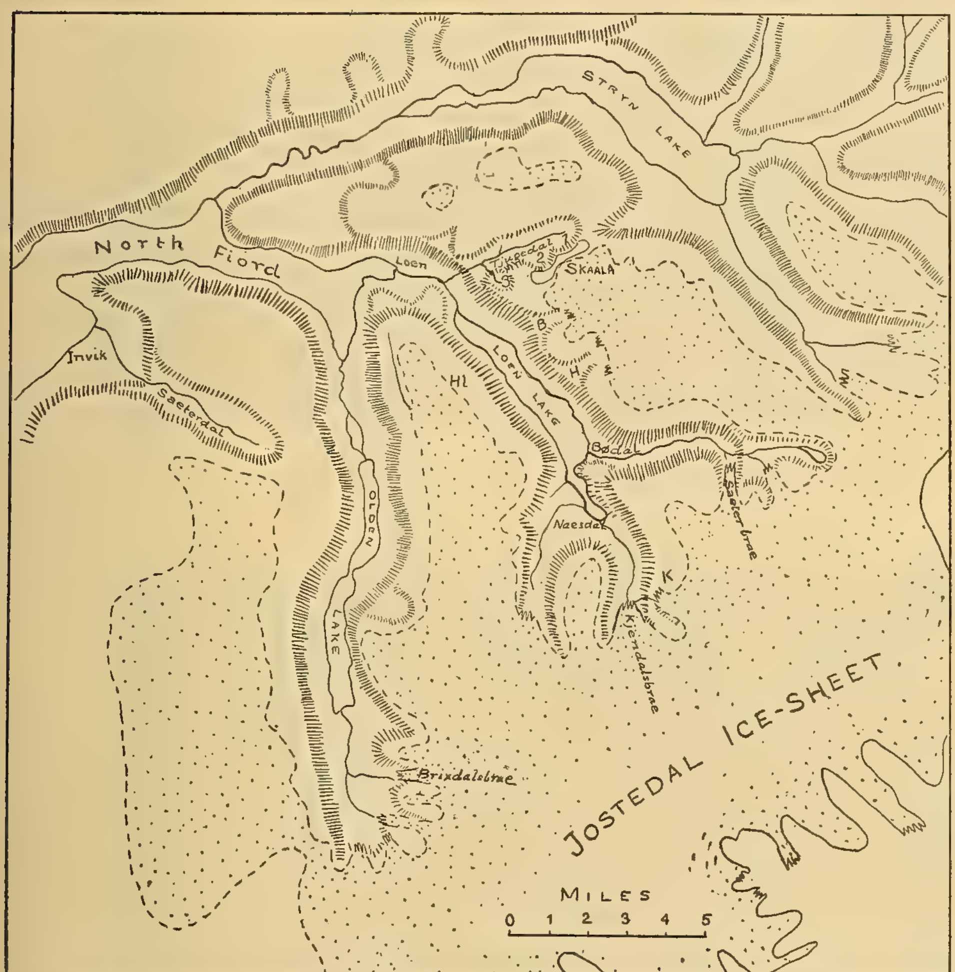

FIGURE 2.—*The Loen and Olden Lakes.*

The Tongues of the Jostedal Ice Sheet

KJENDALS GLACIER

Three miles above the head of Loen lake, Kjendalsbrae in part falls over a cliff of rock, in part flows down a steep incline. Below, it gathers again into a true glacier on a gentle slope. Its erosional effects are very disappointing. There is no moraine. The ice point, which is about 100

feet high, rests on the boulders of the valley floor, unencumbered. Of late years the ice has been retreating. About a mile from the ice is a line of moraine, shown in figure 1, plate 40. It contains no fine material; only boulders like a large but discontinuous stone wall. The difference of vegetation on the up and down-stream sides is more striking than the wall itself. Plainly the glacier stood here not many years ago. The lower ledges for 500 yards along the valley are somewhat smoothed, yet have not that degree of smoothing that we are accustomed to associate with glaciers and which we see on the weather-stained ledges of this same valley farther down or at this same point, about 1,000 feet above the valley floor. One ledge that was only 100 feet in front of the ice and very probably covered by it last year or the year before was very much shattered and its points rather bruised than rounded. Glaciated pebbles such as abound in our tills were not found. The best had only the rudest sort of rounding. Pebbles there were innumerable, but mostly as sharp and angular as if they came from a stone quarry. The freshness of all rock surfaces and the abundance of fragments, large and small, showed that erosion is going on; the sharpness of all fragments and the shattering of the ledges suggested plucking rather than grinding. The rock is a hard gneiss. This ice tongue makes its mile of descent in about three miles, and faces north. The water that flows from the ice is of a greenish milkiness, like that of the Loen lake and the head of the fiord itself.

BRIXDALS GLACIER

About 10 miles from Kjendals over the ice sheet, Brixdalsbrae (plate 41) descends toward the west into the head of the Olden valley in a continuous slope from the towering Jostedalsbrae above to a level 960 feet above the sea, unbroken by any cliff. It is therefore much cleaner in its lower part than the Kjendalsbrae, which contained many blocks of stone. At Brixdals there were none. This glacier is actively grinding and polishing its bed and shaping its boulders and pebbles. Along the whole 2½ miles that its valley reaches back from the main Olden valley, the abundant boulders are rounded and glacially planed. At the head of the main valley, too, lies an ice tongue, the Maelkevoldsbrae. A little below the junction of the two valleys is an old moraine of enormous angular blocks, black with weather. I estimate some of them at 40 feet on an edge. All the detritus is black and weathered to within 2 miles of the ice; thence fresh, gray, and unweathered as at Kjendals. Glaciated boulders a foot or more in diameter are easily found; smaller ones are not so abundant and show no striæ, owing probably to the granular character of the rock.

FIGURE 1.—LOOKING OUT FROM THE HEAD OF THE NORTHFIORD

The scenery in that direction is rather mountainous than canyon-like

FIGURE 2.—MORAINE BELOW KJENDALSBRAE

The moraine resembles an old stone wall. The lack of vegetation to the right indicates a recent retreat of the ice front

NORTHFIORD AND THE MORAINE BELOW KJENDALSBRAE

There is no moraine at the ice front. It rests for the most part on clean ledge; so at the sides one sees the ice quite clean and free from ground moraine where it projects over points of rock. At such places the ice is grooved to take the shape of the ledge, and fragments of rock, ground to the consistency of coarse sand and gravel, lie in front. At the places where this was observed the ice had not 50 feet of thickness. The thickness of the middle of the tongue was estimated at 240 feet by aneroid measurement on the rocks above and at its base. There is not merely a greater thickness of ice, but the thrust from above caused greater effect here than at Kjendals.

The ledges at Brixdal are of gneiss in layers that slope 10 or 15 degrees toward the glacier. In ascending these layers a good deal of polishing has been done, sufficient to cause the morainal boulders, sand, and gravel that rest loosely on them to slip readily. These surfaces are distinctly striated all over. I should think the ice must have passed over them even last year, to judge by the precarious attitude of this stuff and the crusty clinging together of the coarse sand. There is no other definite moraine in the valley than the huge blocks referred to. Neither here nor at Kjendals was seen any equivalent to the clay of our tills. Coarse sands were seen in the streams and the waters are milky greenish, doubtless with matter held in suspension, but it is not perceptibly clearer at the outlets from the Olden and Loen lakes, though these are 8 or 10 miles long. Penck (1879) noted this absence of terminal moraines in some Scandinavian glaciers visited by him, and pointed out that what is present is often not really terminal moraine at all, but merely lines of boulders thrust together from the valley floor at times of glacial advance. This, however, is not always the case.

SAETER GLACIER

Northeast of the Kjendalsbrae, at a distance over the ice and mountains of about 4 miles, is the Saeterbrae, ending 2,000 feet above the sea in the canyon-like Bødal valley by which it must be approached from Loen.

The floor of the valley is of fine gravel, ascending pretty regularly for 3 miles from the lake, when it begins to flatten and give place to meadows lying between lines of real terminal moraine. Both times I visited them it was raining hard, but they seem real moraine to me, continuous ridges of dirt and stones running across the valley in long lines, some of them 30 feet high. I have seen neither planed nor striated pebbles in them, nor clays. In the brook in this valley I found the finest and softest sand deposits of the region.

The glacier descends to the northward like the Kjendalsbrae, is continuous, of gentle descent, very dirty, symmetrically crevassed, and seemed to have something like a lateral moraine of gravel along its east side, though this was only glimpsed through cloud and mist. The crevassing of the ice front gives it a jagged outline, within many of whose notches lay tiny lakes. The ice lay on gravel free of moraine at the present front. No ledge is visible at any point of the valley floor; but the brook, cutting deeply, about 2½ miles up from the valley mouth encounters ledge far below the floor, which is here represented by grassy benches above.

The Hanging Valleys

REFERENCE TO ORIGIN OF HANGING VALLEYS

As I understand the view of hanging valleys current in this country, they are tributary valleys whose floors are high above the main valley floor at or very near the point of junction, a small tributary glacier eroding its valley less than the greater one in the main valley. There seems to be implied the condition that they lead from catchment areas smaller than those supplying the main valley. They have themselves been eroded by the ice tongue from this small névé field. Their "hung up" character is thought to result from the difference in erosive power in the two valleys. The level of their mouths would seem to be fixed by the magnitude of the ice stream that they contain. It is not, therefore, necessary that adjacent ones lie at the same height above the valley floor. Three side valleys of this sort seem to occur near the head of the Northfiord (see figure 2). More numerous examples occur of the botner (or cirque) type, draining only their own area, with no névé field behind, and eating headward into the mountain side at about the level of the snow-line, and some of them long and valley-like.

OVER BODAL

Near the Saeterbrae hangs what seems to be a small tributary valley, its mouth several hundred feet up the valley wall. It is floored with an alternation of bog and lee-and-stoss-shaped ledges, excellently glaciated. Into it descend the glaciers from Lodalskaupe. The stream on its floor has done little cutting. It very likely received less ice than the main valley, which comes from the great snowfield more directly. I have not visited the end of the valley, which was hidden in rain and mist the day of my visit, but it is shown on the maps to contain a lake.

This is in contrast to the other hanging valleys of the region. All the others have gravel filling for floor.

PRAESTEDAL

This has a strong notch cut back by its stream to a valley floor 2,000 feet above the sea. It opens on an amphitheater at Invik on the fiord about 7 miles west of Loen. Its floor extends 3 or 4 miles from the lip to head, in a wall of rock under Cecilienkrone. There is no glacier in the valley—only the botners that have burrowed into its wall, high up on the south side. Under these descend long talus slopes to the boggy meadow of the valley floor. The point where the stream leaves the upper valley was apparently a line of old gravel moraine which laked the upper valley and brought about its filling until the moraine is fairly buried. Along the crest of this moraine now stands a line of saeters or summer-pasture dwellings. The surface of the valley is a pure red peat, which colors all the small streams strongly. The main river has cut through it and flows beautifully clear on a bed of gravel.

The amphitheater at Invik, on which Praestedal opens, has several distinct terraces, the highest about 500 feet above the sea. In this valley, too, the only ledge is that revealed deep in the cut made by the stream. The valley does not head toward a continuous upland, but toward the deep Olden valley, hardly a mile distant from its head. It is difficult to regard it as a tributary valley to the Northfiord from this fact, that it does not lead toward it from a possible névé field.

The most striking hanging valleys of the region are the three on the northeast side of the valley of Loen between Loen and Bødal. Of these Tjugedal overhangs the 140-foot terrace of Loen and the valleys of Brengsnaes and Hogrending (B and H on figure 2) overhang the Loen lake. They open out on the steep valley wall at elevations of about 1,800 feet.

VALLEYS OVER BRENGSNAES AND HOGRENDING

These were only seen from below in repeated trips up and down the lake, and once from a point about 1,700 feet up on the opposite valley wall. They attract attention by the volume of water that they send down the steep cliffs. To judge from these distant views, both have their floors filled with gravel, from which rise long slopes of gravel-like talus. The streams flow in notches in these gravel floors. From the opposite wall I estimated the elevation of the Brengsnaes valley at 1,900 feet, that at Hogrending at 1,800. To judge from the map and what can be seen from below, which is not, of course, a satisfactory way to study such forms, the two are good illustrations of hanging valleys that have orig-

inated in the way alluded to as the current explanation. They do not seem to head against cliffs, but to slope gently back to the outlying fields of the Jostedals glacier, tongues of which lie in them up toward an elevation of 5,000 feet. They were tributary valleys because fed only by this outlying snowfield, which could never supply an ice stream of the volume delivered into the main valley by the great névé field.

TJUGEDAL

This valley was visited and four days spent in its study and that of the neighboring cliffs. It opens on the valley wall at a height of about 1,700 feet, the stream coming down abruptly on ledge from 1,400, visible in repeated foaming falls, but between retiring into deep recesses carved in the rock. At the valley mouth the water runs deep cut into the rock, with long slopes of bare gravel leading up some hundreds of feet to benches on right and left. This material resembles a loose till, yet has no striæ or certain planing on the pebbles, and the sections visible were all open to suspicion of slipping. All up the valley the stream was deeply cut in these gravels. They do not give a plane valley floor, but one concave to the sky in cross-section. The long section is convex, descending at a slope of 5 degrees in its upper part, which has increased to 15 degrees at the mouth of the valley. Here the plunge is made down a descent so strong that although a path has been cut zigzagging up it, it is still one of the most toilsome climbs of the region (plate 41, figure 2). Three miles back the valley heads up at a cirque wall, its foot at 3,500 feet and the crest 600 or 700 feet higher.

SKAALA GLACIERS

On the south the lofty knife-edge of Skaala overhangs at 6,500 feet, descending by strong black cliffs to twin botner glaciers. These are set deep into the mountain mass, and by their bowl form give it the name (*skaal* = bowl). Their huge moraines form a terrace on the south side of the valley floor. At the valley head lies a snowfield about a mile long, but stagnant, with beautifully clear water issuing from the stones beneath its lower edge and forming there a tiny lakelet. The surface of this snowfield inclines toward a low point near its center, with an appearance of flowing in from all sides. The gurgle of running water is heard underneath at many points. No ledge is visible here save in the walling cliffs and in the deep cut made by the stream. There are lines of moraine across the valley. There is no abrupt change of slope from valley floor to rock wall. It is not impossible that the filling is largely talus from the valley sides. Vegetation in the form of deep mosses, heaths,

FIGURE 1.—HELLSAETERBRAE

The upper ice cone is built of fragments that fall every hot summer afternoon with thunderous sound. It lies half-buried in a hollow in the mountain side

FIGURE 2.—HANGING VALLEY OF TJUGEDAL

View is taken from below. Note the notch that the stream has carved in the gravels of the valley floor

HELLSAETERBRAE AND HANGING VALLEY OF TJUGEDAL

and an occasional dwarf willow abounds well up toward 4,000 feet. The birches were all left below the valley mouth.

Botner glaciers, usually longer than wide, abound in this region at elevations above 4,000 feet and northerly exposure. They have no appearance of being remnants of former tributary valley glaciers, but appear to have originated as patches of ice on the mountain side. They gave me a distinct impression of eating into the mountain side as a strong acid might eat into iron. They are strikingly contrasted to the tongues of the great Jostedal ice sheet in possessing enormous moraines at their lower ends. These moraines are often greater in bulk than the mass of ice that seems to have made them. This is true of the Skaala glaciers of Tjugedal (figure 2, 1 and 2). They lie side by side on the mountain side like a pair of spectacles, a huge pillar of black rock rising nose-like between them. They measure about 1½ miles from extreme east to west and half a mile or so from front to back. The rock behind rises a thousand feet in a precipice whose lowest part is the freshest and steepest, as if the ice had lately and suddenly sunk into the rock. Below, the two run together again near the elevation of 4,000 feet. Isolated under the ice foot is another snow mass of conic form, the result of summer avalanches. The moraines are of great volume and moss-covered and much weathered in the outer parts, which have the form of wall or rampart, while those nearer the ice are fresh and unweathered. Gravel makes the greater part of these moraines, but large stones are not uncommon in the upper part. One was found 18 inches long, well planed and striated, and a number show traces of glaciation; but this is not characteristic. Clay is not present. Even in the plain of deposit which the stream is building within the lines of moraine, the finest material is but a gritty sand. In the main Tjugedal stream, however, I found a very fine deposit on the stones.

The crest of Skaala above the glaciers is a ridge about 60 paces wide and 1,200 long, falling steeply on the south side also to an outlying field of the great ice sheet. The snow supply of the Skaala botner glaciers does not come to it from the mountain above, but is limited to what falls on their surfaces. Viewed from across the valley, these and similar glaciers look like the work of some great burrowing animal, the moraine representing the excavated stuff lying in front of the burrow. A little west of these lies another botner (3, figure 2) on the south wall of Tjugedal, but without a glacier, its foot at 3,500 feet. The snowline of the Loen region is near 5,000 feet, varying a good deal, of course, for local reasons of slope and exposure; but there are no bare areas of importance above that level.

The Skaala glaciers, facing northward, reach down below 4,500 feet. Above 4,000 feet water rarely runs. A little patch of snow lay at the back of this second botner, behind the lakelet of its rock basin, but is probably not perennial. This botner is the bowl of little Skaala through which the ascent to the crest of the mountain is made. Most of its floor is occupied by an extensive field of broken stones, naked and somewhat weather stained, under which water is heard running. This is in part frost-shattered ledge, in part moraine from another botner that opens into it behind and above. There is no moraine at the botner mouth, nor resting place for it short of the valley floor, 1,500 feet below.

Over across the Tjugedal valley, on the northern border of the snowfield that lies near its head, an abundant talus of fine rocky fragments rests against a strong, firm cliff of gneiss. From below one sees nothing but bare cliff above, but from the opposite crest of Skaala two botner glaciers are seen to lie just over the shoulder of the valley wall. The Skaala botners would probably overhang the valley by several hundred feet if the ice were out of them, as the two on the north side are over 1,000 feet up and the little Skaala a good 1,500, having been excavated probably when the snowline lay 600 or 700 feet lower than now. Here, then, are hanging valleys that have originated by excavation at various times and heights in the walls of a valley already excavated.

HEADWARD EROSION OF HANGING VALLEYS

Tjugedal itself can hardly have any other explanation. It is not the valley through which a snowfield drained. There is no snowfield at its head. Like the Praestedal, it heads against a thin wall of rock that alone separates it from the deep valley of Stryn. The snow and ice that passed through it have always been what fell within its walls. Some ice may have cascaded into it once by the valleys of little Skaala, but this entered near the mouth, and can not have helped greatly in the excavation of the valley, and it is likely that at the time the snowline was low enough to fill the main valley with ice the stepped botner valleys in the sides of Tjugedal were not yet existent.

It is not inconceivable that some weakness of rock structure may have guided headward erosion along it while the snowline was rising from the 1,800-foot level represented at the mouth to the 3,500 one at the head wall by the process of sapping at the contact of ice and rock in the zone of constant freezing and thawing. Such a process should cause a botner to widen as well as deepen, as each wall should recede, and this process is at work on the Norwegian plateau today, reducing every summit that projects above the general level, as Richter has pointed out. The Skaala

and Lodalskaupe are good examples in the Loen region of fragments still surviving this form of attack. Headward erosion by this process seems only possible in a valley if there be an axial weakness to work along. Had the process gone a little farther the head wall must have broken down and a high level cross-canyon resulted between the valleys of Loen and Stryn. The interest of this possibility is in the abundance of cross-fiords and valleys in west Norway and the difficulty of explaining them on a scheme of pure ice erosion. In the Bergen region, where these are very systematically developed at right angles to the line of continental glaciation, the geologic map shows the cross-valleys are typically the outcrops of sedimentaries and other apparently weaker rocks among the gneisses.

The easiest botner to visit in Norway lies in the outskirts of Bergen, overhanging the Svartediget precisely on the line of an outcrop of fine-grained quartzose gneiss mapped by Doctor Kolderup (1902) as far as the opposite wall of the valley, and declared by him certainly a sediment. The layers stand vertical at the lip of the botner and are axial to it. Bergen itself lies in a ten-mile-long valley a thousand feet deep in the upland, but curving around in a crescent along an outcrop of Silurian rocks starting from and returning to the sea. Such valleys, when their floors are under water, are as much fiords as those that run from the land seaward and as characteristic. That these have sometime ended in a botner amphitheater of rock is an assumption; but the valleys described do, and a continuation of activities that have not entirely ceased in these valleys would certainly make of Praestedal and Tjugedal cross-valleys such as abound.

It is reasonable to suppose that Tjugedal may once have served as a partial outlet valley for the ice of the Skaala outlier of the Jostedal glacier, much as the valleys over Brengsnaes and Hogrending seem to do today, but the valley of that day must have lacked the botner head that characterizes it now, and its length was less by all that headward erosion has given it since.

The corrosive attitude of the ice as it lies on these uplands is nowhere better exemplified than in the mountain on the border of Stryn lake, a little north of the Tjugedal. As seen from Hjelle, across the lake, the snow lies sunken into the mountain top as if in the crater of a volcano—an appearance often seen in the arctic regions. The details of this sort of erosion have been cited by Russell (1887) from Lorange. A similar aspect is present in the Hellsaeterbrae (Hl, figure 2) on Loen lake (figure 1, plate 41), which falls in huge masses from a cliff summit 4,000 feet above sealevel into two snow cones. The upper one is sinking

into a pit on the mountain side, whence flows the stream that has built the huge fan of excavated material on the shore of the lake; the lower caps the fan with snow-ice from the cone above. The falling of water has doubtless aided here in digging the pit. All along Stryn lake botners are seen; all along the Northfiord they are sighted, not remnants of valley glaciers, but pockets of ice eating their way into the mountain.

Origin of Botner-like Fiord Heads

The fiord heads themselves, in which lie the great ice-tongues from the Jostedal glacier, head up in the same amphitheater form. Plate 42 shows [sic] this for the Brixdalsbrae; Kjendals, Kvandals, and the Maelkevoldsbraes show the same thing. The headward branches of the Northfiord are three or four thousand feet deep within a mile or two of the great ice sheet on the plateau. It is difficult to think of the erosion of a sixty-mile-long canyon by a plucking, grinding ice stream in this extraordinary form, almost equally deep from mouth to source. The width has diminished by a half or two-thirds from sea to head, the depth but a fourth to a third.

Richter (1896) has pointed out that the process of carving the great fiords is quite different from that by which Alpine valleys have been made, and refers most of their excavation to the interglacial periods. The ice river below carried off the fragments that frost and other subaerial agents strip from the walling cliff, and a stagnating ice sheet above mainly served to protect the plateau surface from erosion. These were the agents at work when the ice was diminishing after a period of intense glaciation. These conditions are still present at the fiord heads. The material excavated here is sufficient to make a flat filling that floors the head of the valley to unknown depths—spread out thus in the enormous volumes of water that issue from the melting ice.

Erosion on Lofjeld

Some notion of the style of erosion that is going on beneath the ice-sheet may be had by examining lower border parts of the upland from which the ice has now withdrawn. The only place at which this was done was the mountain top that overhangs Loen, the Lofjeld, the part of the Skaala outlier of the Jostedalsbrae that lies west of the Tjugedal. It is now bare of ice except in a few sheltered spots. It has a rounding summit at 3,800 feet. The crest is of ledges of gneiss, glaciated from south 70 degrees east to north 70 degrees west. This comes out in rounded lee-and-stoss forms. The motion was parallel to the fiord. No

BRIXDALSBRAE

Showing the blunt end characterizing the heads of the branch valleys at the head of the Northfiord

striæ were seen, the forms of the ledge being about as much weathered as the summits of the Belknaps at 2,000 feet elevation in southern New Hampshire. The lee side is completely shattered by frost into a mere heap of fragments.

On the stoss side, to north and east, is a vast gray wilderness of shattered blocks, mostly angular and none suggesting glaciation. The rock is not greatly weathered. There is none of the solar effect, the splitting off of little chips of surface rock revealing the fresh rock below, as the heat of sunshine was following by night radiation under a clear sky, which is familiar on southern faces in the Belknaps and in the drier south of Norway near Kristiansand. Both effects are probably much hindered by the prevalent cloudiness and abundant precipitation characteristic of all of west Norway north of the sixtieth parallel.

At Loen but 12 days of 50 were clear. In Germany the summer of 1904 was one of great and unusual drouth. At Kristiansand the heather was withered and burned brown in all the shallow pockets of the rocks; at Loen there was overabundant precipitation. It is the custom at Kristiansand to cure hay on the ground. In the glacier region it has to be hung on fences built for its curing.

Running Water and its Work

It would be difficult in the Loen region to get out of sight and sound of running water. There is a point on the Olden lake where one may see 14 considerable streams descending from heights of 2,000 or 3,000 feet, making great leaps in the air, and then disappearing in clefts in the rock. Below the snowline rock faces everywhere glisten with water. Level surfaces are either covered with snow or wet and boggy with quaking peat. To leave the highway is to put one's feet in water.

The Brengsnaesvoss, issuing from one of the hanging valleys of the Loen lake to descend 1,800 feet of cliff, shows an extraordinary feature about 1,000 feet above the lake. From below this appears as a curious leap and tuft of spouting water, but on ascending it is seen that the water has bored a deep pothole in the rock and, falling into this, has force enough to leap again 25 feet into the air before turning far out over the cliff, which it does not again touch for a long distance. That these streams cut actively is attested by the very large fans of detritus that project into the lake below them. That they often glide over the surface of the rock without any channel is a consequence of the steepness of the wall. That frostwork is of great effect may be imagined. Nearer the sea the milder oceanic climate deprives the water of this effect. Ber-

gen has 70 inches of rain, but has known no temperature under 5 degrees Fahrenheit, and sheer cliffs of gneiss there, as on the face of Blaamanden 1,000 feet above the city and fully exposed to the Atlantic winds, stand almost without talus at their foot, with hardly a scar on the purple weathered rock.

Unweathered Detrirus

The most striking evidence of the high erosive activity of the Norwegian streams is the fresh, light-colored detritus that they handle. The Northfiord gneisses weather to a dull purplish red, being light gray when fresh. Many of the side tributary streams, like the Tjugevoss, carry only gray boulders, pebbles, and sand in their bed. As I have already stated, only fresh unweathered rock is seen, either as ledge or detritus for a mile or two from the glaciers at the heads of the fiord. Above the snowline the frost-shattered blocks are not thus fresh. Discolored felspars, with pink and reddish tints, are characteristic, attesting a long stay on that spot.

Conclusions

I saw in the Northfiord moderate evidence of a glacier's power to grind its bed of rock with rock fragments for tools, some hanging valleys that may be the work of tributary valleys, as in the current explanation; more that seemed due to the enormous headward erosion of botner glaciers near the snowline; great activity of frost at all levels away from the coast and of running water below four or five thousand feet above the sea, operating to carry rock waste seaward so rapidly that it had little chance to weather during the trip.

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STRATIGRAPHY AND STRUCTURE OF THE UINTA RANGE*

BY F. B. WEEKS

(Presented by title before the Society December 29, 1906)

CONTENTS

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Introduction

The geologic history of the Uinta region has been described by King and Emmons in the reports of the U. S. Geological Exploration of the Fortieth Parallel, and of the eastern portion by Powell in his Geology of the Uinta mountains. For more than 30 years these reports have comprised the extent of our knowledge of this interesting section. Recently Berkey published in the Proceedings of this Society an account of a reconnaissance in the Duchesne region and discussed the bearing of his observations on the stratigraphy and structure. The 40th Parallel geologists had studied the ranges of northern Nevada and Utah, while Powell's previous work had been in the Grand canyon of the Colorado and the plateau region of eastern Utah. The nomenclature and correlations of the two explorations varied considerably.

Having taken part in several reconnaissance trips in Nevada and northern, central, and western Utah in previous years, I was able during the summer of 1906 to extend this work over the Uinta range. About six weeks were devoted to this reconnaissance, which extended from the Wasatch mountains along the southern flank of the Uinta to the vicinity of Vernal, Utah; thence, crossing the range to the north, a side trip was made to Red creek, about 25 miles east of Green river; thence, returning westward, it followed the north slope and around the western end to the

starting point. The route of travel followed closely the strike of the Paleozoic strata.

Geography

GENERAL FEATURES

The Uinta range as an orographic feature is a unit. It is a broad, anticlinal arch of horizontal or of slightly tilted strata 25 to 35 miles in width and 130 miles in length. The fold is not, however, wholly symmetrical, since there are regions of faulting and abrupt change to steep dips. It is limited on all sides by Tertiary strata, which abut against or

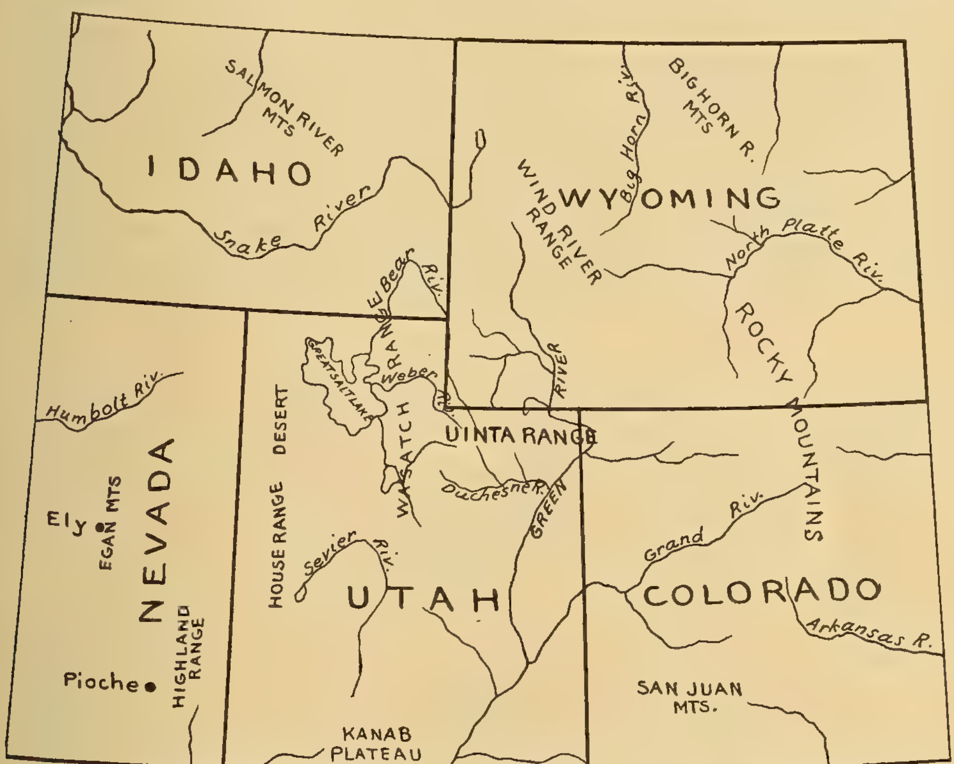

FIGURE 1.—*Sketch Map of Uinta Range and related Areas.*

overlap its slopes except on the west, where it is covered by lava flows Its culminating peaks and ridges extend in an east-west direction along the northern side of the broad summit of the arch. At the eastern end the fold is broad, but broken by sharply compressed folds and faults, while at the western end it narrows to a width of 10 to 12 miles. The plateau-like summit has been deeply dissected and eroded into jagged peaks and ridges having immense amphitheaters at their bases, widening out and then closing into deep glacial-cut canyons through the upturned

Paleozoic and Mesozoic beds which form the anticlinal slopes. Its average elevation is 9,000 to 11,000 feet and many peaks exceed 13,000 feet, the highest being Kings peak, 13,498 feet.

CENTRAL AREA

This region, varying from 10 miles in width on the west to 12 or 15 miles on the east, is formed of the horizontal strata of the "Uinta" formation more or less buried beneath debris not yet removed by erosion since the melting of the glaciers. Hundreds of lakelets and ponds, held in their rocky basins by accumulations of debris, still remain and grassy parks and forest-covered areas occupy the greater part of this region. The axis of the fold follows the northern rim of this central area, trending in general with the peaks and ridges which form the crest of the range. The general character of this area is that of a basin 10 to 12 miles in width, having a very uneven floor and hemmed in by bold escarpments 1,000 to 2,000 feet in height. To the south of the axis the streams heading in the numerous amphitheaters have cut channels of constantly increasing depth until where they pierce the inclosing walls they flow in canyons 2,000 to 3,000 feet deep.

SOUTHERN SLOPE

The slopes which form the south side of the fold are moderately steep, the underlying Paleozoic strata dipping 12 to 20 degrees and the Mesozoic strata at higher angles up to 45 degrees. These slopes have been deeply incised by the few main streams which drain the great interior region. The main drainage of this area is accomplished through many small streams heading in the Paleozoic strata cutting them at right angles, but frequently following along the strike of the softer and more steeply upturned Mesozoic beds. The drainage of nearly the whole southern slope finds its way into the Duchesne river, a branch of Green river. The eastern end of the uplift is drained by small streams flowing directly into Green river.

NORTHERN SLOPE

This region differs materially from the southern slope. The "Uinta" sandstones or quartzites and the overlying formations, for a considerable portion of the area, are buried beneath morainal ridges supporting a thick forest covering or beneath the overlap of Tertiary sediments. The glacial cirques and amphitheaters are relatively small and the streams heading in them have cut canyons 2,000 feet deep within 5 to 6 miles of the crest of the range. These streams flow north and east into Green

FIGURE 1.—BALD MOUNTAIN AND BROAD SUMMIT OF UINTA RANGE

FIGURE 2.—EAST-WEST RIDGE EXTENDING ALONG NORTHERN SLOPE OF UINTA RANGE

CERTAIN TOPOGRAPHIC FEATURES OF THE UNITA RANGE

"ROCK STREAM" NEAR SUMMIT OF RHODES PLATEAU

river except the Bear and Weber rivers, which flow north and west and empty into Great Salt lake. In contrast with the southern slope the strata are upturned at rather steep angles within a short distance of the axis of the fold. The massive bedded Lower Carboniferous limestones form a bold east-west ridge extending for many miles. Figure 2, plate 43, shows this ridge where it is cut through by Beaver creek.

WESTERN END OF THE RANGE

At the western end the range becomes much narrower, the limbs of the anticline increasing in dip. The Uinta and Wasatch ranges are separated by the depression of Kamas valley and the irregular group of hills formed of intrusive andesite and extrusive andesite and breccia. The highest points in this part of the range average 10,500 feet in height, and the slopes gradually descend from 10,000 feet to 6,500 feet, the elevation of Kamas valley, in a distance of 5 miles.

EASTERN END OF THE RANGE

This portion forms a broad plateau of horizontal or of slightly tilted strata with an average elevation of 9,000 feet. This simple structure changes to a very complicated one, following in general the course of Green river. Prominent northwest-southeast ridges mark the line of disturbance on the north side and sharp folds and dislocations on the south side at varying angles to the general east-west folding. To the east of Green river there is a considerable depressed area covered by Tertiary sediments.

Landslides and "Rock Streams"

The phenomena of landslides include variations from the common type of talus slope to blocks of strata displaced en masse by sapping of the underlying rocks. They are of frequent occurrence, especially on the southern slope of the Uinta range. The most striking form of landslide is that described as "rock streams" by Cross and Howe (7)* in the San Juan region of Colorado. Similar phenomena occur near the summit of Rhodes plateau north of the West fork of Duchesne river and on Farm creek. A typical "rock stream" is shown on plate 44.

The material forming the landslide contains blocks varying in size to 10 feet in diameter, derived from the lower part of the Weber quartzite. The slide is probably due to sapping of the underlying limestone in the cliffs, and when the ice melted in the gulches the support was removed and the quartzite strata were detached as a "stream" of rock. The "rock

* The numbers refer to numbers in the list of references at the end of this paper.

stream" ceased its movement, preceded by little if any transportation by ice.

These accumulations of rock do not have the smooth, regular lines of the ordinary talus slope nor the familiar form of terminal moraines. They more closely resemble a fall of rock fragments from a cliff, but in these instances the movement must have been as a mass and not as detached rock fragments.

Geology

GENERAL SECTIONS OF WASATCH, UINTA, AND GRAND CANYON REGIONS

The tables following are comparative generalized Paleozoic sections by King, Walcott, and the writer.

GEOLOGIC MAP

The base of the geologic map, figure 2, is that of the 40th Parallel map. The writer is responsible for the geology except for the region east of Brush creek and Green river, on the south side of the range. This was copied from the 40th Parallel map.

GENERAL FEATURES

The basement rocks upon which the earliest sediments were laid down are not exposed, and no lava flows or intrusives are involved in the uplift. The oldest sedimentary rocks form the broad top and upper part of the anticlinal slopes and each succeeding stratum passes beneath a later one in regular order of deposition.

The section extends from the pre-Cambrian to the Cretaceous, inclusive. It consists of sandstones, limestones, and shales, essentially conformable in structure, although certain members are absent by non-deposition and possibly by erosion.

Subsequent to the uplift a considerable part of the fold was buried beneath Tertiary sediments, which have in great measure been removed by erosion during later Tertiary or Quaternary time. Remnants of such deposits have been left on the higher parts of the flanks of the range, and in some areas completely cover the lower slopes. Quaternary deposits of glacial origin lie on the older sediments of the interior, and fluviatile gravels and sands occur in terraces overlying the younger sedimentary strata. The stratigraphy is in part similar to the succession exhibited in the central Wasatch region and the canyon of the Colorado, but it presents also many distinctive local features.

The Duchesne river has cut a deep canyon in the strata which form this range. In figure 3 is given the section as exposed on the west side of the

neralized Paleozoic Grand Canyon Section after Walcott (6, page 50).

iation.	Character.	Thickness.	Age.
	Shales and marls with impure limestones at base.	*Feet.* 854	Permian.
imestone...	Massive cherty limestone passing into calciferous sandrock	805	Carboniferous.
ındstone...	Reddish sandstone passing into compact beds.	1,485	Carboniferous.
limestone.	Arenaceous and cherty limestone with massive limestone beneath.	962	Carboniferous.
utte lime-	Impure limestone	94	Devonian.
....	Calcareous and arenaceous shales and sandstones.	1,050	Cambrian.
....	Shales and limestones.. 5,120	12,950	Algonkian.
ıyon......	Sandstones with lava flows 6,830		
....	Bedded quartzite and schists.............. 1,000		

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Generalized Paleozoic Wasatch Section after King (3, page 248).

Formation.	Character.	Thickness.	Age.
		Feet.	
Permian............. Upper Coal Measures.	Clays and argillaceous limestones. Light blue and drab limestone.	650 2,000	Carboniferous
Weber quartzite.....	Compact sandstones and quartzites.	6,000	
Wasatch limestone ...	Heavy bedded blue and gray limestones with interbedded quartzites at top.	7,000	Carboniferous. Waverly. Devonian.
Ogden quartzite......	White and pink quartzite and conglomerate.	1,000	Devonian.
Ute limestone........	Compact blue limestone and argillites passing into shales.	1,000	Siluvian.
	Quartzites, slates, and schists .	12,000+	Cambrian.

Generalized Paleozoic Section in the Uinta Range (Weeks).

Formation.	Character.	Thickness.	Age.
		Feet.	
Permo-Carboniferous	Red shales .... 860 Light gray sandstones.. 1,050 Red shales and dark blue limestones...... 660	2,570	Permian.
Weber formation....	Yellow calcareous sandstone, white and gray quartzite, weathering brown.	2,200 to 2,700	Pennsylvanian.
Mississippian series.. (Upper part Pennsylvanian series).	Alternating beds of white sandstone and limestone; thin bedded blue and gray cherty limestones and massive dark green and buff limestones at base.	700 to 1,070	Mississippian.
Ogden quartzite....	White and greenish massive quartzite and green sandstones with interbedded conglomerates.	0 to 1,100	Ordovician.
Lodore shales.......	Argillaceous and sandy green, red, purple, and black shales; green shales containing many nodules.	500 to 1,200	Cambrian.
"Uinta" formation.	Thin bedded green sandstones with conglomerate layers, striped quartzites, and red and brown quartzites or sandstones, base not exposed.	12,000+	Pre-Cambrian.

Generalized Paleozoic Grand Canyon Section after Walcott (6, page 50).

Formation.	Character.	Thickness.	Age.
		Feet.	
Aubrey limestone...	Shales and marls with impure limestones at base. Massive cherty limestone passing into calciferous sandrock	854 805	Permian. Carboniferous.
Aubrey sandstone...	Reddish sandstone passing into compact beds.	1,485	Carboniferous.
Red Wall limestone.	Arenaceous and cherty limestone with massive limestone beneath.	962	Carboniferous.
Temple Butte limestone.	Impure limestone	94	Devonian.
Tonto	Calcareous and arenaceous shales and sandstones.	1,050	Cambrian.
Chuar .... Grand Canyon...... Vishnu............	Shales and limestones.. 5,120 Sandstones with lava flows .... 6,830 Bedded quartzite and schists............. 1,000	12,950	Algonkian.

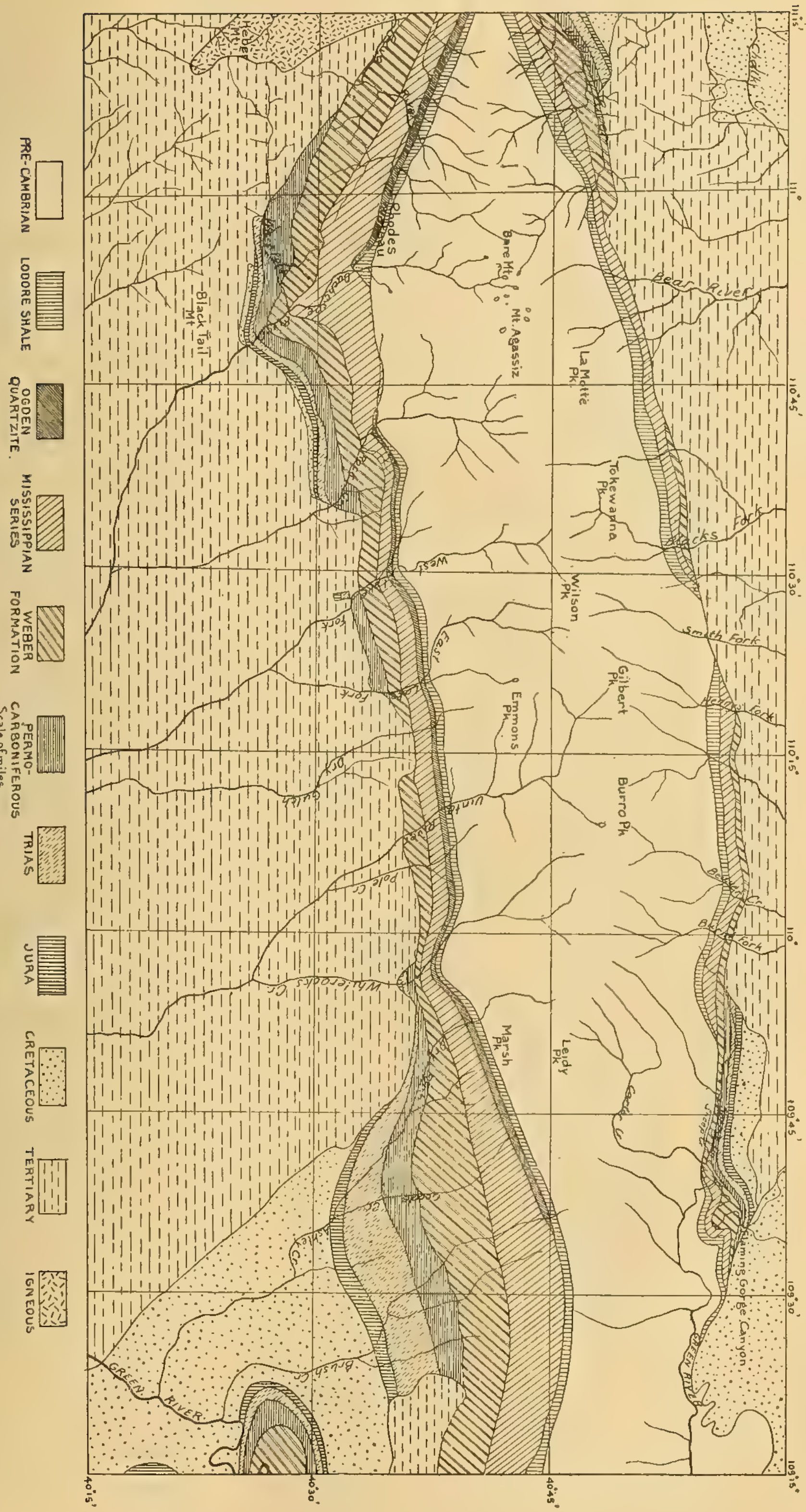

FIGURE 2.—*Geologic Map of Uinta Range.*

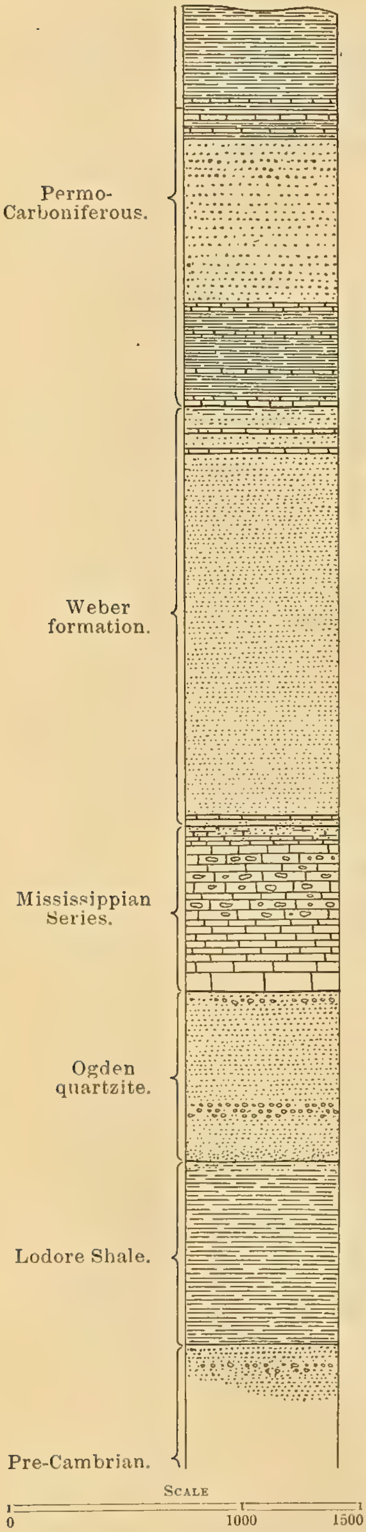

Figure 3.—*Section on Duchesne River, below Iron Creek.*

river about two miles below Iron creek, extending from the Lodore shales to the Weber formation at the summit of Rhodes plateau and the Permo-Carboniferous beds exposed on the east side of the river below the mouth of West fork. This section shows the variations in character of Paleozoic sediments, except as noted hereafter.

PRE-CAMBRIAN "UINTA" FORMATION

Nomenclature and correlation.—The oldest sedimentary strata of the Uinta range were named and defined by Powell as the Uinta sandstone. King applied to this series the name Weber quartzite, considering that it corresponded in stratigraphic position with the Weber quartzite of the Wasatch mountains. It has recently been decided (10) to retain the name Uinta for the Tertiary strata which forms the plateau region east of the Wasatch and south of the Uinta ranges. The decision was made on the grounds of priority and general usage. No new geographic name is proposed for this formation, leaving the question of nomenclature for future discussion. In this connection it may be stated that it is believed not to be the best practice to retain a name indefinitely applied and used for general description where the same name has been applied to and adequate description given of another series of strata to which the name is more applicable. King states (3, page 407): "Uinta group was a term stretched for convenience to cover all the Tertiaries south of Uinta range of whose true subdivisions we were ignorant." The name Uinta as applied to the Tertiary strata of the Duchesne drainage area is a misnomer, while no one would question its application to the great thickness of quartzite and sandstone forming the surface rocks of the Uinta range for approximately 2,000 square miles.

The character of the rocks and the stratigraphic position and thickness of the quartzite series suggest that it is to be correlated with the great quartzite sections of the Wasatch and other ranges of Utah and eastern Nevada whose position beneath the Olenellus shales of the lower Cambrian is generally recognized. No fossils whose stratigraphic position is known have been found in this formation. The oldest fossils are of Lower Mississippian age, but are separated from the "Uinta" quartzite by 500 to 1,200 feet of shales. While the correlation seems to rest on inconclusive evidence, it should be remembered that there is no other known series of such extent and thickness with which it can be correlated.

Description.—This formation constitutes the broad top of the range. At the eastern end the folding is less pronounced and the overlying Mississippian limestones form the surface rocks. At the western end the formation is covered by lava flows in Kamas valley, but is again exposed on the western slope of the Wasatch range. The base of the formation is not exposed, but its thickness exceeds 12,000 feet. In the western part of the range, especially on the northern flank, the strata are very compact, dense quartzites. In other parts there are all gradations to a soft sandstone. The prevailing color is reddish brown, with a considerable thickness of purple quartzites about the middle of the formation. The upper part contains striped quartzites, and in both eastern and western parts of the range there are several bands of interbedded conglomerates with greenish sandstones at the top. In some areas white quartzites are well developed, particularly in the Green River region. One of the most favorable localities for the study of this formation is along the east side of the East fork of Smiths fork of Green river, on the north side of the range. The beds dip 25 to 40 degrees to the north, and are exposed in continuous section to and including the Lodore shales about one mile above China lake.

CAMBRIAN LODORE SHALES

Nomenclature and correlation.—In Lodore canyon of Green river Powell noted the occurrence of 500 feet of shales between the "Uinta" sandstone and the Aubrey limestone, and designated them Lodore shales. He correlated them with the Tonto shales of the Grand Canyon region, and stated that Carboniferous fossils had been found in them. The names of the species or locality where found are not given, and there is considerable doubt as to the accuracy of this statement. Walcott considers that the Tonto shales are of middle and upper Cambrian age. In my reconnaissance no fossils were found, although considerable time was devoted to searching for them at numerous localities where the shales

were favorably exposed. In stratigraphic position and lithologic character the beds are very similar to the Tonto shales. Their position above the "Uinta" quartzite corresponds to that of the shales above the quartzite series in Big Cottonwood canyon in the Wasatch mountains. The latter, however, are only 150 feet thick, contain the Olenellus fauna, and are overlaid by Cambro-Ordovician strata. According to the available evidence, it is believed that the Lodore shales represent the deposits of Cambrian time in the Uinta region. This formation was not differentiated by the 40th Parallel geologists.

Description.—The Lodore shales constitute a series of argillaceous and sandy green, red, and purple shales overlying the greenish sandstones which form the upper part of the "Uinta" quartzite. In some parts of the series lamination is not well developed and they resemble mud beds. Many nodules and a marked tendency to nodular structures characterize the green shales wherever exposed. The formation is well exposed on Kamas creek, Provo river, and upper Duchesne canyon. In this region the formation in its upper part varies considerably from fine to coarse sandy or conglomerate beds (plate 45), and the transition to the succeeding formation is through beds of finer grain, altered into quartzite. The thickness varies from a maximum of 1,200 feet on Duchesne river to 500 feet on Green river. In passing eastward the beds become thinner by the disappearance of the sandy beds at the top. Along the northern slope of the range the formation is mainly shale from 400 to 500 feet thick and well exposed on Green river and its tributaries. On Carter creek, a few miles east of the point where it empties into Green river, there is a fault of considerable displacement which brings the "Uinta" quartzite against the Weber formation. To the west the formation is nearly everywhere covered by glacial debris as far as Weber river, where it is well exposed in Smith and Moorehouse and South Fork creeks. Throughout the Uinta region the Mississippian series overlaps the Lodore shales and Ogden quartzite, but appears to overlie them in conformable position.

ORDOVICIAN OGDEN QUARTZITE

Nomenclature and correlation.—This formation was named and defined by the geologists of the 40th Parallel Survey, and considered by them to be Devonian in age. In its typical locality, Ogden canyon, and in sections east of Cache valley, Utah, the writer in 1906 found fossils above and below this formation and also in interbedded limestones in the lower part of this formation, determined by Mr E. O. Ulrich, which show that this quartzite is of Upper Ordovician age. In the Wasatch mountains the quartzite varies from 800 to 1,200 feet in thickness and rests upon

LODORE SHALES IN HADES CANYON

Hades canyon is in the first right hand fork above West fork of Duchesne river

Cambro-Ordovician limestones. It is overlaid by 200 to 300 feet of Silurian and Devonian limestones, at least in the Cache Valley region, as shown by fossils collected by the writer in 1906 and determined by Messrs Ulrich and Kindle. In the Uinta range the Ogden quartzite rests upon the Lodore shales, considered to be Cambrian in age, and is immediately overlaid by limestones of Lower Mississippian age. This formation was not differentiated by the 40th Parallel geologists in the Uinta region.

Description.—The formation is well exposed along the south side of the range from Kamas creek to Whiterocks creek. The basal beds are greenish sandstones, above which are several beds of fine-grained conglomerate and cross-bedded sandstone. These are succeeded by 200 feet of white quartzites. The upper part of the formation contains beds of conglomerate and a prominent band of calcareous sandstone two to three feet in thickness, which grades into buff weathering limestone of the overlying Mississippian series.

No representative of the Ogden quartzite was determined on the north side of the range, as the Lodore shales appeared to pass directly into the Mississippian limestones. This seems a peculiar circumstance, since the quartzite is 1,200 feet in thickness in Ogden canyon, 1,000 feet or more in Weber canyon, and 800 to 1,000 feet in Big Cottonwood and American Fork canyons, in the Wasatch mountains, which are not more than 25 to 40 miles from the western end of the Uinta range.

CARBONIFEROUS

Mississippian series—Nomenclature and correlation.—The 40th Parallel geologists recognized that the great quartzite-sandstone series of the Uinta range were the oldest sediments and conformably succeeded by the overlying beds, but by correlating the series with the Weber quartzite of the Wasatch mountains it necessitated the correlating of the Mississippian limestones with the strata above the Weber quartzite; consequently they did not recognize the presence of the Wasatch limestone.

Wherever fossils have been found in the lower and upper members of the Wasatch limestone, they show the former to be of Mississippian age and the latter of Pennsylvanian age. This is also true of the Uinta range. The precise line of division has not yet been determined. In the Uinta range about 600 feet of the 1,070 feet of beds that have been correlated with the Wasatch limestone are certainly of Mississippian age. Powell correlated the beds of the Wasatch limestone with his Grand Canyon section. They correspond in general to the Red Wall group.

Description.—The basal beds of this series are buff, blue, and gray limestones, weathering darker in color and some of them have a decided greenish tinge. They are usually in massive, brecciated beds having a thickness of 150 to 200 feet. Beside the brecciation or fracturing, many small faults occur in them. The succeeding beds, 6 inches to one foot thick, are buff-colored crystalline limestones having a total thickness of 300 feet, followed by 25 feet of thinner bedded, dark blue, and purple limestones containing a large amount of dark-colored chert. The fossils found in the above described beds indicate that they are of Mississippian age.

The lower beds form bold, massive outcrops in nearly every canyon on both slopes of the range. Where broken by faulting of fractured, they contain gold and silver associated with iron deposits; but little is known of their value. Prospecting in these beds was in progress in several canyons in the summer of 1906.

Pennsylvanian series—Nomenclature and correlation.—This series comprises the upper part of the Wasatch limestone and the Weber formation. No name is given to the limestones of this series occurring beneath the Weber formation, leaving it for future detailed work to determine the beds which are to be assigned to this formation. In the Wasatch mountains a similar succession of strata is exposed. In Powell's Grand Canyon section, Lower Aubrey group and the Yampa sandstone of the Upper Aubrey group correspond to the Pennsylvanian series. The limestones below the Weber formation are to be correlated with the Lower Aubrey limestone, and the Weber formation with the Aubrey sandstone of Walcott's section. So far as the faunas are known, they corroborate these correlations.

Description.—The strata forming this subdivision are 300 to 500 feet of light blue and gray limestones containing a considerable amount of light-colored chert, interstratified with fine-grained light gray sandstones which toward the top contain bands of sandstone weathering brown and resembling in marked degree the weathered material of the "Uinta" sandstone. These are succeeded by the quartzites of the Weber formation.

Weber formation.—The lower part of this formation is a white and gray to greenish quartzite in thin and thick beds, some of which weather brown. In the upper part of the formation are alternating blue and white siliceous limestones and quartzites. The transition to the next series is through blue and reddish limestones and shales. The greatest thickness occurs on the south side of the Weber river, on the north slope of the range. To the east, on this side of the range, the formation is largely covered by Tertiary sediments or glacial debris. On the opposite

WEBER FORMATION, WHITE ROCKS CREEK, UINTA RANGE

WEBER AND PERMO-CARBONIFEROUS BEDS, HORSESHOE BEND, GREEN RIVER

(south) side of the range the formation is well exposed in all the principal canyons from the Provo river to Green river. This formation, like the "Uinta," is quartzitic in the western and central parts of the range and grades into a rather soft sandstone in the eastern part. No fossils were found in the Weber formation.

Permian Permo-Carboniferous—Nomenclature and correlation.—The Permo-Carboniferous series of the Uinta range seems to correspond in position, thickness, and general lithologic characters to the Upper Coal Measure and Permo-Carboniferous formations of the 40th Parallel Survey. On similar grounds they may be correlated with the Aubrey limestone of Walcott's Grand Canyon section. The correlation with Powell's section is less definite. The limestones overlying the Yampa sandstone of the Upper Aubrey group and an undetermined thickness of the shales and soft sandstones of the Shinarump group appear to correspond to the beds under discussion.

Description.—The upper beds of the Weber formation are calcareous sandstones and siliceous limestones which weather yellow and grade into the thin red shales and red and blue limestones of the upper part of the Permo-Carboniferous series. This series is well exposed on the Duchesne river, Rock creek, Whiterocks creek on the south side of the range, and in Horseshoe canyon of Green river on the north side of the range.

One of the best sections occurs on the east side of Duchesne river below the mouth of West fork. There the lower 600 feet of the Permo-Carboniferous are formed of the red and purple shales and blue limestones. Above is 1,000 feet of light gray and white sandstones, with some interbedded limestones in the lower part. In the upper part these sandstones occur in alternating layers of soft and compact beds full of peculiar black points or specks. These are succeeded by 800 to 900 feet of red shales, with a prominent band of light-colored shale at the top.

POST-PALEOZOIC

Trias.—The Trias was defined by Emmons (2, page 200) as consisting of red sandstones with a series of clayey beds at the base, having an estimated thickness of 2,500 feet. Powell (1, pages 150-153) did not separate the Jura from the Trias. He divided the Jura-Trias beds into the Shinarump, Vermilion Cliff, White Cliff, and Flaming Gorge groups, having a total thickness of 3,845 feet. The Trias of the 40th Parallel Survey appears to correspond to the Shinarump, Vermilion Cliff, and White Cliff groups of Powell. The writer has classed the shales at the base of the Trias with the Permo-Carboniferous. The line of division between the Trias and the Permian is placed at the base of the massive cross-bedded sandstones.

In the Uinta uplift the Trias, Jura, and Cretaceous strata are largely covered by Tertiary sediments or glacial debris. The principal areas of outcrop are in the Flaming Gorge canyon of the Green river, on the north side of the range, and in the canyons of Green river in the vicinity of Split mountain and Ashley and Dry Forks creeks, and on the Duchesne river several miles below the mouth of West fork, on the south side of the range. The Trias is much thicker in the eastern part of the range. In the western part the clayey beds of the upper part of the Trias were apparently not deposited. The coarse cross-bedded sandstone, 300 to 400 feet thick, is a dark buff color in the Duchesne region, which varies to lighter color to the eastward.

Jura.—The Jura is composed of sandstones, shales, and clay beds, with a prominent limestone series having a maximum thickness of 200 to 300 feet, the whole averaging from 600 to 800 feet in thickness, as determined by the 40th Parallel Survey (2, page 200). The Flaming Gorge group of Powell (1, page 152) is considered to represent the Jura. The writer considers the prominent drab limestones to form the base of the series, the remainder of the Jura being formed of the overlying sandstones, shales, and clays.

The areas of outcrop of the Jura in the Uinta uplift correspond to those of the Trias and appear to have a greater thickness of beds in the eastern part of the range. In the Duchesne valley the Jura is represented by a compact drab or gray limestone and soft red calcareous shales. The transition from the buff or brown cross-bedded sandstone of the Trias to the Jurassic oolitic and granular limestone is made in less than ten feet of strata.

Cretaceous.—This system is divided into the Dakota, Colorado, Fox Hills, and Laramie groups, to which are assigned 10,000 feet of sandstones and clays by the geologists of the 40th Parallel Survey (2, pages 200-202). Powell (1, pages 153-161) divides the Cretaceous into the Henrys Fork, Sulphur Creek, Salt Wells, and Point of Rocks groups. The areas of outcrop correspond to those of the Trias and Jura. The writer, not having had opportunity to study these areas, is unable to add materially to previous descriptions.

Tertiary.—The Tertiary strata of the Uinta and adjacent areas have been described by the 40th Parallel geologists (2, pages 202-325) and divided into the Vermilion Creek, Green River, Bridger, and Uinta groups and the Wyoming conglomerate. Powell (1, pages 161-172) has divided the Tertiary into the Bitter Creek, Lower and Upper Green River, Bridger, and Browns Park groups and Bishop Mountain conglomerate. The Tertiary strata which have been deposited around the Uinta uplift

have never been studied in detail, and but little definite data regarding their lithologic or stratigraphic divisions are available. Bluffs and ridges of these strata from the sides of the alluvial valleys and small remnants occur along the mountain slopes, reaching elevations of over 10,000 feet. Along the south side of the range the lower members are grits and conglomerate passing into finer grained sandy and calcareous beds.

Interpretation of the sedimentary Record

No representative of the basement complex is known in the Uinta region. The 12,000+ feet of the "Uinta" formation, 1,200 feet of Lodore shales, and 1,100 feet of the Ogden quartzite have not yielded fossils. On lithologic and stratigraphic grounds the "Uinta" formation is considered to represent the sediments of pre-Cambrian time. The Lodore shales represent a period of sedimentation in which from 2,000 to 4,000 feet of Lower, Middle, and Upper Cambrian shales and limestones were deposited in the Central and Northern Wasatch and Grand Canyon sections. In the Wasatch region approximately 3,000 feet of limestone and quartzite were deposited in Ordovician time, while in the Uinta region a maximum of 1,100 feet of sandy beds were laid down during the same period. On the northern flanks of the Uinta range, in the Green River region, the shales are reduced in thickness to 500 feet, the Ogden quartzite is absent by non-deposition, and the Mississippian limestone is about 700 feet in thickness. This marked thinning of sediments eastward, by which the sedimentary section is reduced in thickness several thousand feet, indicates an overlap upon a land-mass which, in central Wyoming, brings the Permo-Carboniferous beds unconformably on the Crystalline schists.*

Unconformities in the Uinta Region

Powell recognized an unconformity at the top of the Uinta sandstone. The overlying shales are said to fill hollows in the unevenly eroded surface. This unconformity was not noted by the 40th Parallel geologists, and C. A. White (4, page 23), who was associated with Powell in his later work in this region, has stated that the indications are so slight as to be readily overlooked. No satisfactory evidences of such an unconformity were found during the past field season. In every locality examined throughout the range the Lodore shales were found conformable above and below with the associated strata, except in Duchesne and Rock Creek canyons and in the vicinity of Green river, on the northern slope,

* Darton: Personal communication.

where the shales have been faulted and the relations of the formations can not readily be determined.

On the northern flank of the eastern Uinta several bands of conglomerate are interbedded with the "Uinta" sandstones, and have considerable areal extent. They are well exposed in cliffs, have the same strike and dip, and form an integral part of the "Uinta" series.

Berkey noted (8) an unconformity by erosion within the Carboniferous, and suggested that by a withdrawal of the sea slowly westward and a more rapid readvance to its former boundaries the erosion interval in the Green River region noted by Powell should be extended to include the sedimentary period represented by 6,000 feet of strata, as shown on his (Berkey's) columnar section. Observations in this field do not, however, support the hypothesis. It has been found that, with the exception of the Ogden quartzite, the sedimentary series is remarkably uniform throughout the whole extent of the Uinta region. The absence of the Ogden quartzite may be due to the presence of a land mass, the Uinta fold being then in an incipient stage. The evidences of unconformity at the base of the Carboniferous Weber quartzite are inconclusive, as, contrary to Berkey's observations, no basal conglomerate in this series was noted in the Uinta area. Occasionally there is a small development of shales, but the transition from the underlying limestone to quartzite is usually through light gray fine-grained sandstones.

The Tertiary overlaps all the older strata, including the great interior quartzite series, reaching a maximum elevation of 10,000 to 11,000 feet.

Structure

In General

Regarding the structure of the Uinta uplift, King (3, page 753) makes the following summary statement:

> "It [the Uinta uplift] consists of a broad central plateau 150 miles long by 30 miles wide, in which there are slight sags and local undulations, but the average dip of the strata is from the horizontal only up to 4 or 5 degrees. This broad, flat-topped arch suddenly gives way along the north and south edges to two distinct axes of flexure where the horizontal rocks bend over, accompanied by distinct faulting at angles varying from 10 to 70 degrees. In the Green River canyon the southern line of flexure becomes immensely complicated and develops three local anticlinals."

Powell does not present a summary of his conclusions, but I have gathered together the following: The Uinta mountains have been produced by the degradation of a great upheaved block having its axis in an east-west direction. The displacement is partly by faulting, partly by flexing.

The region was upheaved partly as an integer and partly as a body of minute parts. With upheaval degradation progressed. We are led to conclude that a maximum rate was not established; that as upheaval was slow, degradation was slow.

Berkey (8) notes the occurrence of a persistent and important fault on the upper Duchesne, and states that toward the east the major fault cuts higher up in the series, at least above the Carboniferous.

Faults are of frequent occurrence along the strike of the Cambrian shales, which seems to have been a line of weakness. In some instances the fault is a normal one; in others the overlying limestones appear to have been thrust over and covers in whole or in part these shale beds. Where the shale beds are not faulted the strain seems to have been relieved by compression in the Weber and overlying Permo-Carboniferous strata. As a rule, the Paleozoic beds have a shallow dip 12 to 20 degrees, while the Mesozoic beds which form the outer slopes of the fold usually dip at 40 degrees. On the northern slope, in the central region, the "Uinta" quartzite and overlying Cambrian and Carboniferous beds are steeply upturned, while in the eastern areas the "Uinta" is nearly horizontal or dips 5 degrees or less, and the higher beds are faulted or steeply upturned.

GENERAL STRUCTURAL FEATURES OF SOUTHERN SLOPE

The fault which crosses the Duchesne river at the mouth of Iron creek is a normal one. At the head of the West fork of Rock creek the same fault has developed into a thrust. On the West fork of Lake fork the fold is symmetrical, except that the Weber and Permo-Carboniferous strata have been sharply plicated and compressed. The section in White-rocks canyon exhibits similar plications in the same strata, and there is also a small amount of faulting in the shale series.

Subsequent to the main folding there has been a warping by which the general east-west strike varies from northwest-southeast to northeast-southwest at various localities.

GENERAL STRUCTURAL FEATURES OF NORTHERN SLOPE

The general east-west strike of the beds varies locally as on the southern slope.

Where the Weber river cuts through the Paleozoic strata the beds dip 80 degrees north, and in the Weber formation there is developed locally an overturn of these strata. In this region the strata of the "Uinta" formation dip 5 to 10 degrees to the north, with a sudden steepening of dip in the beds beneath the shale series. To the east the inclination of the "Uinta" strata increases in the direction of the axis of the range.

In plate 48, the high peak near the center background is mount Lovenia. From this point to the right side of the photograph the direction is north-south, and shows the position of the anticlinal fold on the north side of the highest portion of the range. In mount Lovenia the beds dip south 4 to 5 degrees; in the high ridge between the two peaks the dip is 10 to 15 degrees north; in Tokewanna peak the dip is 25 degrees, and still farther down the ridge to the north of Tokewanna peak the dip increases to 45 degrees north, and continues at this dip until covered by the overlap of Tertiary strata.

On the ridge at head of the East fork of Smiths fork and on the ridge leading up to Gilbert peak, the strata dip south 5 degrees. A fault or sharp fold in the strata is here developed and the beds dip 30 degrees north, increasing to 45 degrees, well exposed on the east side of Smiths fork.

The area between the crest of the range and the prominent limestone ridge drained by the headwaters of Beaver creek and Burnt fork is formed of heavily forested morainal ridges which completely mask the structure. From Leidy peak the axis of the anticline follows closely the ridge forming the divide between Ashley and Brush creeks on the south and Carter creek on the north, crossing the Green river and terminating in the faulted and flexed strata of O-wi-yu-kuts plateau. Throughout this area the beds of the "Uinta" formation dip to the north 3 to 10 degrees.

Near the headwaters of Sheep creek a fault develops which brings the nearly horizontal "Uinta" beds against the steeply upturned beds of the Weber formation. From the horseshoe bend of Green river east to and including the O-wi-yu-kuts plateau the fault becomes a series of sharply compressed folds, with occasional faultscarps having a general east or southeast trend. The upper beds of the "Uinta" formation are involved in this plication, the beds being metamorphosed into schists and quartzites, and comprise the Red Creek quartzite of King, Emmons, and Powell, and referred by them to the Archean. East of O-wi-yu-kuts plateau the beds dip steeply northeast, with a northwest-southeast strike.

On the opposite (south) side of the range there are several anticlinal folds also indicating a compression at right angles to the major fold of the range. The stratigraphy and structure of the eastern end of the range have been described in detail by Emmons (2, pages 262-298).

EXTENT OF MAJOR FOLD

The general anticlinal structure of the Uinta range extends from the west face of the Wasatch range to the foothills of the Park range in Colo-

HEAD OF BLACKS FORK

Axis of fold north of crest of range

rado. The Wasatch and Uinta ranges are separated by Kamas valley and a group of irregular hills formed of extrusive andesite and breccia. In the Wasatch range the fold is broken by the granite intrusion and associated rocks forming the peaks and ridges about the headwaters of Little and Big Cottonwood creeks. On the north side of this intrusive mass the sedimentary rocks dip to the north and northwest and the anticline pitches down beneath the Salt Lake valley. On the south side the steep south or southeast dips change rapidly to an average dip of 5 to 10 degrees, and in American Fork canyon a secondary fold occurs with a northwest-southeast trend.

The axis of the Uinta fold trends a little north of east as far as Leidy peak, and occupies a position north of the crest of the range (see plate 48). From this point the trend is east to the O-wi-yu-kuts plateau. In the Green River region the fold is broken by a thrust movement having a general northwest-southeast strike and changing to east-west on both the north and south slopes of the range. East of this region the fold is much less prominent and is largely covered by later deposits. This portion of the uplift has been described by C. A. White (5).

OTHER SIMILAR FOLDS

Until within recent years it has been supposed that the Uinta range was the only fold in the Cordilleran region having an east-west trend. Darton has described (9) a similar fold forming the Owl Creek range. Recent work in central Wyoming by the same geologist has shown the occurrence of several folds having the same trend.

While the major folding of the eastern and central Cordilleran region varies in trend from north-south to northwest-southeast, there was a considerable crumpling of the crust in the opposite direction. So far as observations have been made, both movements seem to have occurred during approximately the same geologic period.

AGE OF THE FOLDING

It appears to be generally considered that the orographic movement which in great measure determined the position and direction of the Rocky Mountain and Central Cordilleran ranges developed after the deposition of the last marine Cretaceous strata and prior to the deposition of the fresh-water Eocene sediments. Observations during recent years indicate that this interval represents a long period of geologic time. There was profound faulting and folding and upthrusting of the crust which mark this as one of the great periods of mountain building of the earth's

history. Subsequently, in late Tertiary or Quaternary time, there were minor readjustments.

Degradation

Powell in his Geology of the Uinta mountains has discussed the degradation of the Uinta range. It seems probable that from the Archean to the close of the Cretaceous, except during Silurian and Devonian time, there was continuous subsidence and sedimentation in this region. With the inauguration of the continental uplift and the change to fresh-water conditions, sediments were deposited over the uneven floor, filling the hollows and overlapping all the older formations, which continued through Tertiary time and possibly early Quaternary. A thickness of several thousand feet of brackish and fresh-water sediments accumulated, reaching an elevation of 10,000 feet on the northern slope of the Uinta range and 8,500 feet on the southern slope. During Glacial and post-Glacial time to the present erosion has been very rapid. The flanks of the range have been largely denuded of the Tertiary covering. Huge morainal ridges, extending several miles beyond the base of the range and burying large areas of the Tertiary strata, and even the older rocks, are prominent features of the region at the present time.

Geologic History

The sediments of pre-Cambrian time in the Uinta range consist of a great thickness of sandstones, and a similar series occurs to the west as far as the Sierra Nevada, extending with some variations from Montana to southern Nevada. To the east the same character of sediments were deposited, but greatly reduced in amount. Beginning with Cambrian time and continuing through the lower Paleozoic, there was great diversity in the character and conditions of sedimentation. In the Great Basin province, including the northern and southern Wasatch, there were deposited several thousand feet of shales, sandstones, and limestones in Cambrian and Ordovician time, and in the same region considerable deposits were laid down in Silurian and Devonian time, thinning to the eastward from central Nevada. In the central Wasatch the Cambrian is thin, but there is a considerable thickness of Cambo-Ordovician sediments known as the Ute limestone and Ogden quartzite. In the Uinta region the Cambrian sediments are shales, and a small representative of the Ordovician quartzite occurs. Similar deposits of varying thickness are known to occur in various sections in Colorado and Wyoming extending as far east as the Black hills. Throughout the region extending from the

Wasatch to the Black hills there was, however, a relatively small amount of deposition in the aggregate from Cambrian to the Devonian, inclusive. It was a period in which no marked earth movements developed. The land areas were of considerable extent, but of low altitude, and the shorelines were extended or receded slowly, and no extensive series of sediments were laid down as compared with those of the Great Basin region. With the beginning of the Carboniferous, however, there was a marked change. The Mississippian sea transgressed as far as central and southern Nevada, and in the eastern Cordilleran region comparatively uniform conditions of sedimentation prevailed to the close of the Trias. In the Uinta region the Mississippian and overlying limestones, the Weber quartzite or sandstones, the Permo-Carboniferous standstones and shales, the Triassic sandstones, and the Jurassic limestones and shales were deposited. With the beginning of the Cretaceous the sea receded to the Wasatch. To the west of this range no later marine sedimentary record is known. In the Wasatch and Uinta region a considerable thickness of Cretaceous sediments was laid down. In post-Cretaceous time the great orogenic movements were inaugurated which resulted in elevations giving rise to the Uinta range and others to the east. Upon the flanks of these ranges and in the depressions a great thickness of Tertiary sediments was subsequently deposited.

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ORIGIN AND SIGNIFICANCE OF THE MAUCH CHUNK SHALE*

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(Presented in abstract before the Society December 26, 1906)

CONTENTS

PART I. OBSERVATIONS BEARING ON THE PROBLEMS OF ORIGIN

INTRODUCTION

A discussion of the nature of geographic and climatic control of sedimentation has been previously made by the writer in order that the origin of certain specific formations might be dealt with, and the present paper on the interpretation of the Mauch Chunk follows these previous articles in logical sequence.†

* Manuscript received by Secretary of the Society from Censor October 28, 1907.

† Relative geological importance of continental, littoral, and marine sedimentation. Journal of Geology, vol. xiv, 1906, pp. 316-356, 430-457, 524-568.

Relations between climate and terrestrial deposits. Presented before the Geol. Soc. Am. December 26, 1906. Printed in abstract in the Proc. Geol. Soc. Am.

The first part of the present paper consists of a presentation of the significant facts of the Mauch Chunk shales, gathered both from the literature and from personal observation. The second part deals with the interpretation of these facts. Where a new view is to be proved the observational and inferential portions should be strictly separated, but at the same time the purpose for which the facts are presented should be evident when they are given. It is therefore desirable to state in advance the conclusion finally reached, which is that in the anthracite region, more surely in the southeastern and eastern portions, the whole formation, from top to bottom, was a subaerial delta deposit laid down under a semiarid climate.

Besides merely the essential facts, there are included in the descriptive portion many details which are not used in drawing the conclusions, but which, if the hypothesis of terrestrial deposition be accepted, are interesting as showing in a definite case what the minor characteristics of such a formation may be. They are doubtless also valuable as indicating specific features of climate or geography, even though their significance may not at present be understood.

GENERAL DESCRIPTION OF THE MAUCH CHUNK FORMATION

The Mauch Chunk shale is the name of a strongly individualized formation of the Lower Carboniferous of Pennsylvania, chiefly consisting, in the region of its typical development, of alternating red shales and red sandstones, the ratio of the two varying through different horizons of the formation and in different districts.

Not a little of the distinctive character of the Mauch Chunk is due to its sharp contrast with the preceding and succeeding formations. The inferior, the Pocono sandstone, consists of a great thickness of grayish green to light gray, cross-bedded sandstones, the whole weathering white and constituting a massive and resistant formation, topographically prominent wherever it occurs. Above the Mauch Chunk lies the Pottsville conglomerate, interstratified with gray sandstones. The Pottsville, like the Pocono, is a resistant formation and one to whose protecting rim many of the smaller synclinal coal basins owe the preservation of their coal during the Tertiary cycle of erosion. In contrast with these adjacent formations the Mauch Chunk as a whole is weak and consequently readily reduced to local base level. It yields a red loamy soil, and where the formation is thickest, as around the southern and middle anthracite coal basins, gives rise to comparatively level and broadly open valleys. These are utilized for agriculture, and the checker-work of fields contrasts strikingly with the forest-covered and level-topped slopes

which rise on each side to a height in the neighborhood of a thousand feet.

The broader characters and relations of the Mauch Chunk shales of Pennsylvania and the synchronous deposits of other portions of the Appalachian basin have been recently so admirably summed up by J. J. Stevenson* from the previous studies of himself and others that only sufficient need be here outlined to bring the chief features to mind.

The formation in question was laid down with a character, thickness, and distribution much more variable than that of the underlying Pocono. Its maximum development occurs in the anthracite coal regions and it there possesses its typical character. Beyond the limits of the state of Pennsylvania the equivalent formations are so different that other names must be applied. In eastern Ohio the strata pass into the upper part of the Waverly group, while to the southwest in Maryland and Virginia the Greenbrier limestone occupies the horizon of the lower portion of the shales. In contrast to the considerable thickness to the south, the shales are thin along all the northern outcrops in Pennsylvania and often missing from between the Pocono below and the Pottsville above.

The Mauch Chunk reaches its greatest thickness in the region of the southern anthracite coal field, according to Rogers measuring at least 3,000 feet at Pottsville. At Mauch Chunk, Winslow gives figures of 2,168 feet on the south side of the syncline and 3,342 on the north. From these maximum thicknesses it diminishes northward to 1,000 feet at Solomons gap, near Wilkes Barre, and 150 feet of green shales and flaggy sandstones at Pittston. Passing westward from Pottsville, first to the Broad Top coal field, Ashburner and Billin give it a thickness of 1,100 feet, divided into: 1, Upper shales and sandstones, 910 feet; 2, Mountain (Greenbrier) limestone, 49 feet; 3, Lower shales and sandstones, 141 feet.† Northwest of the Broad Top field and back of the Alleghany Mountain front the thickness is given by Butts, in the Ebensburg, Pennsylvania, folio, as but 180 feet, of which the lower 80 feet consist of thick bedded gray to greenish sandstone, corresponding perhaps to the Greenbrier limestone, and underlaid by 5 to 6 feet of interbedded red shale and sandstone. At the most southwestern outcrop in Pennsylvania, that of Laurel ridge (Masontown-Uniontown quadrangle), M. R. Campbell gives the entire thickness as 250 feet, consisting of three members. At the base are 50 feet of typical Mauch Chunk red shale, followed by 30 feet of Greenbrier limestone, which is in turn succeeded by 170 feet of red and green shales, with occasional beds of greenish sandstone.

* Lower Carboniferous of the Appalachian basin. Bull. Geol. Soc. Am., vol. 14, 1902, pp. 16-96.

† Second Geological Survey of Pennsylvania. Summary, final report, vol. 3, part 1, p. 1833.

It is seen from these details that the edge of the great Greenbrier limestone of Virginia and farther west reaches into southwestern Pennsylvania only, thinning away to a knife-edge, and its place being apparently taken near its margin by thick bedded gray to greenish sandstones, noted as 80 feet thick in the Ebensburg folio.

Recent observations tend to show that over the western half of Pennsylvania, as well as over the states of the central west, uplift and erosion intervened to a greater or less extent between the latest deposits of the Mississippian period and the earliest of the Pennsylvania,* the adjacent formations being sharply distinct and different members of the Mauch Chunk or equivalent formations coming into contact with the Pottsville sandstone. The scantiness of the Mauch Chunk along the northern side of the area appears, however, to have been due largely to the thinness of the original deposition, since nowhere is it reported as more than 100 feet in thickness, and, as may be seen by tracing the formation eastward along the north margin of the northern coal field, the red shales gradually disappear by transition into, and interfingering with, greenish shales and flaggy sandstones of the same character as the Pocono. These facts tend to confirm the idea of H. D. Rogers that the Umbral (Mauch Chunk) shale was never deposited beyond these limits. Some erosion of the upper strata appears to have also occurred, however, preceding the earlier deposits of Pottsville conglomerate and sandstone.

But such an erosion interval with resulting unconformity and stratigraphic contrast between the two adjacent members is absent in the region of the southern anthracite coal field, where there are from 500 to 600 feet of transition beds. These are described by A. D. W. Smith,† who states "at times in these transition beds heavy conglomerates predominate, with but few sandstones and shales, or again the whole series may be composed of coarse sandstones and shales, with the green and reddish tinge running high in the formation, making it difficult, even when a complete section is at hand, to decide where the line between the two formations should be drawn." David White, from the investigation of the fossil plants, concludes that half of the formation in the Pottsville basin was deposited before deposition began in the western part of the state.‡

These facts point to the conclusion that sedimentation was continuous over the Pottsville trough of maximum subsidence. Consequently the

* Chamberlin and Salisbury: Geology, vol. ii, 1906, p. 508.

† Second Geological Survey of Pennsylvania. Summary, final report, vol. iii, part 1, 1895, p. 1921.

‡ The stratigraphic succession of the fossil floras of the Pottsville formation in the southern anthracite coal field. 20th Ann. Rept. U. S. Geological Survey, part ii, 1900, pp. 755-918.

lower half of the Pottsville and upper transitional Mauch Chunk represent a time interval when not only sedimentation ceased over the greater portion of the northeastern Appalachian basin and Mississippi valley, but actual uplift took place, or change in other conditions, such as rainfall, sufficient to result in widespread though not very deep erosion.

THE MAUCH CHUNK OF THE ANTHRACITE COAL BASINS

Stratigraphic characters.—The outcrops of the Mauch Chunk surrounding the southern and middle anthracite coal basins offer favorable opportunities for the study of the formation. In this region it is observed to consist of red shales, often more or less sandy, and red sandstones, often highly argillaceous. Conglomerates are extremely rare, except in the transition beds in the upper part of the formation, where green shales in sparing amount may also be observed. Impure calcite concretions in red, sandy shales occur scattered through much of the formation, but especially the lower half. These concretions are usually nodules from 1 to 2 inches in diameter, which may be so abundant as to form an impure limestone and are apt to be segregated in certain laminæ.

The microscope shows the shales to contain more ferric oxide than the sandstones, as would be expected from the usual association of ferric oxide and clay except where reducing waters have leached out the iron. The colors of the shales are, more accurately, bright brownish reds. The sandstones vary from brownish red to grayish and reddish purple, but usually possess a sufficient amount of ferric oxide to give them a color tone approximating to that of the shales. There is, in fact, in the formation as a whole a marked homogeneity of color. The purer sandstones are, however, in some places delicately banded in color, though still massive in texture, due to very thin laminæ of sand not over a millimeter in thickness, being relatively free from clay, and consequently also from iron. These make handsome building stones, being used for that purpose in many of the finest buildings in the principal cities of the region. Occasionally beds of gray or green shales may also be observed, but not in the body of the formation in the areas of maximum sedimentation.

During the progress of the second geological survey of Pennsylvania, Winslow recorded complete sections of the Mauch Chunk formation at Mauch Chunk on the Lehigh river and at Solomons gap near Wilkes Barre, 24 miles to the north.* These, being made by the same observer, are valuable for illustrating the variations in the formation and are

* Summary, final report, vol. 3, part i, 1895, pp. 1815, 1821.

reproduced here in order that they may be compared. A good section of the transition beds at the top of the Mauch Chunk at Pottsville is given by D. White.*

Sections of Mauch Chunk Shales, Winslow

	Sandstone.	Shales and sandstone.	Shales.
At Mauch Chunk:			
Mount Pisgah, Pottsville conglomerate and sandstone with shaly bands........... 320			
Red shale in the body of the conglomerate.................................. 500			
Lower conglomerate with a green matrix, large quartz pebbles.................. 120			
Upper beds of Mauch Chunk red shale and sandstone..............................		1,662	
Sandstone, yellow and friable..............	83		
Red shale..............................			28
Chocolate colored and gray hard sandstone...	28		
Shales, mostly concealed....................			367
Pocono sandstone..........................			
	111	1,662	395
At Solomons gap:			
Pottsville conglomerate.....................			
Mauch Chunk, red and green shale with calcareous layers..........................			246
Brick red shale..........................			120
Sandstone, reddish gray, with quartz pebbles and also red shale pebbles................	27		
Shale and sandstone, red and massive........		335	
Sandstone, reddish and greenish gray, with fine quartz pebbles.......................	31		
Brick red shale...........................			60
Sandstone, fine, greenish gray, which might be just as well made the top layer of the Pocono as the bottom layer of the Mauch Chunk............................. 183			
	58	335	426

It is seen from these sections that no marked division lines characterize the formation throughout the whole region, though near the bottom in each section is a considerable body of shale. The dominant stratigraphic feature consists in the intimately interstratified beds of sandstone and shale occupying considerable portions of the section where the formation is thick. There are other portions, however, in the same sections in which shale is the principal factor. It is to be noted also that shale

* 20th Ann. Rept. U. S. Geological Survey, part ii, plate clxxxii.

MUD-CRACKS IN MAUCH CHUNK SHALE

West bank of Schuylkill, south of Pottsville. Argillaceous sandstones separated by shale partings. Looking at under side of beds, strata vertical. This view, showing several mud-cracked surfaces, is taken near the bottom of the visibly mud-cracked portion of the section. On the nearer mud-cracked surface note the peeling off of the shale in places and the convexity of the under surface of the shale polygons. Also note the variety and detail in the shale surfaces.

forms a greater ratio of the whole at Solomons gap, where the formation is thinner.

The sandstone members without notable shale are seldom thick, in only one case exceeding 31 feet, and, as observed by the writer, are hard and fine grained. The individual strata possess an average thickness of perhaps a foot, but often of not more than an inch. In the shale sandstone portions the individual beds of sandstone are separated from each other by thin partings of shale. The sandstone strata are continuous over the limits of any one exposure, and no marked bottom channels are to be observed where the sandstone rests on shale. All gradations from hard, somewhat ferruginous sandstones through argillaceous sandstones to sandy shales are abundant. Ripple marks, wave marks, and current marks are common upon the surfaces of the arenaceous beds. Cross-bedding is common, and a small amount of calcium carbonate is frequently present, as shown by calcite infiltrations into fracture planes and as seen under the microscope.

The argillaceous strata where forming thick masses are very seldom well exposed, the weathering of a few years sufficing to cause recently excavated material to crumble into a soft rubbish, as may be observed in the railroad cuttings and fillings. The surfaces of shale where remaining exposed develop such a close and irregular fissility that observations on the original nature of the bedding planes are impossible. Usually such massive shales possess a perceptible amount of siliceous grit, and have resulted from the consolidation of loamy clays. The shale layers may consequently be best studied where they form the partings between the sandstone beds of the shale and sandstone members, having been protected from weathering in such places by the more resistant strata. Detailed examination was made by the writer, to such extent as time permitted, of the section cut by the Lehigh river at Mauch Chunk, and more thoroughly of the section along the Schuylkill river at Pottsville. The former showed very little structure in the shale beds, while at Pottsville the original structures were excellently preserved. The difference between these two regions is to be ascribed with high probability to the fact that the section at Mauch Chunk cuts across the compressed end of the coal basin syncline. The consequent changes in dip within short distances must have involved during the folding considerable adjustment of adjacent strong beds upon each other, as is in fact testified to by the numerous minor slip planes and fractures in the sandstones. Under such circumstances the shaly partings, while still protected from weathering, seem to have formed planes of adjustment with more or less obliteration by shear of the original features. At Pottsville, on the

other hand, while the strata have been tilted beyond the vertical, the dip is constant throughout the section, and the depth of the bottom of the syncline at that place prevents the present exposed portion from being near the region of changing dip. Observation does not indicate any lateral adjustment between beds.

Inorganic evidences of subaerial exposure.—These shaly partings, as noted by H. D. Rogers, frequently show a glazed surface, which he considers as an indication of the freshly deposited clay having been exposed to the air in a wet state. He further remarks:

> "These glazed surfaces not only sometimes retain the impressions of delicate water marks and groovings such as water trickling down a slimy or wet sandy beach always produces, but are sometimes imprinted with the markings called 'rain spots,' and more rarely the footprints of land animals or cracks filled with sand, such as geologists are wont to attribute to shrinkage in mud from the sun's heat."*

The best exposures among those examined by the writer were at Pottsville, on the west side of the river. The lower 400 feet (estimated) do not show rock outcrops, but from the development of the drainage and the character of the soil the strata are judged to form predominantly, if not entirely, a shaly mass. The middle two-thirds of the formation are more arenaceous and resistant and the vertical strata cut across by the river furnish ideal opportunities for studying the sequence of the beds. The exposures have been increased in recent years by excavations into the cliffs to allow laborers' cottages to be built between them and the roadway, and on account of the rapid weathering of the shale surfaces they are doubtless now at their best.

Beginning with the first good exposures, not more than 500 to 550 feet from the top of the Pocono, the first unmistakable mud-cracked surfaces appear on the incoherent, thin and lustrous, shaly laminæ separating the sandstone beds. In close contiguity with this lowest observed mud-cracked stratum is one of calcareous shale holding lime concretions 2 inches in diameter. The view in plate 49 is taken a little above this horizon. From this point upward through the next 1,500 feet of strata strikingly mud-cracked surfaces are found at short intervals, a view in the upper portion being shown in plate 50, while on many intermediate beds more or less faint patterns of mud-crack polygons may be seen by careful observation. Certain of these would not be positively identified as mud-cracked surfaces were it not for the association with adjacent strata in which they are beyond doubt. In the better instances smooth shale strata are intersected by polygonal ribs of sandstone from sand carried

* Geology of Pennsylvania, vol. ii, part ii, 1858, p. 831.

MUD-CRACKS IN MAUCH CHUNK SHALE

West bank of Schuylkill, south of Pottsville, about the middle of the formation. Looking at under side of beds, strata vertical. Interbedded argillaceous sandstones and shales. Note the convexity downward of the thin shale surfaces. Secondary cracking has occurred, as well as primary.

into the cracks during the deposition of the overlying sand beds. Usually most of the shale has scaled away, leaving the polygonal sandy framework standing slightly in relief.

Where the surfaces of the mud-cracked shale laminæ are well preserved they are frequently seen to be plate-like polygons with raised rims, giving surfaces concave upward. Such warped as well as mud-cracked strata are commonly observed on modern dried mud-flats, the structure resulting from the drying, shrinking, and hardening of the upper side while the lower is still moist. It is seldom that the relations of the shale stratum to the sandstones both above and below are well exposed, either the upper or lower stratum being broken away. In one instance, however, in the middle of the Mauch Chunk formation, where both sandstone layers were preserved, the overlying sandstone passed without interruption down into the cracks and spread out below the shale stratum, filling the space made by the upturned rims of the polygonal disks. These underspaces were about half an inch wide at the middle and tapered to a knife-edge at about 3 to 4 inches each side of the crack, as in the accompanying sketch.

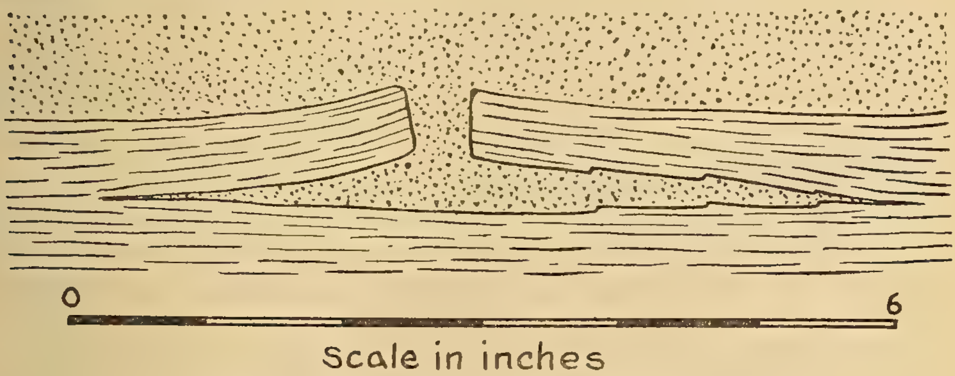

FIGURE 1.—*Detail of Mud-cracks in Mauch Chunk Shale.*

View taken looking at the edge of a mud-cracked stratum from the locality shown in plate 50.

From experiments made by the writer, it does not seem probable that such mud-cracked clay layers could hold up the margins of their disks upon being rewet until the sweep of the waters had filled the underspaces with a clean sand, especially when, as in this case, the mud-cracked strata were of a loamy nature. On the other hand, the structure corresponds to what may be observed on the floodplains of semiarid regions, where during the dry season the channel sands are swept by the winds across the mud-cracked flats, drifting them full of sand and thus preserving them before they are rewet. At places where the cracks are

indistinct or indefinite the rock is usually a thick and fissile, sandy, red shale, the cracks having been filled with material of the same nature. The talus from such an exposure consists of fragments smaller than the polygons, and hence the mud-cracks can seldom be observed upon them. Upon a sufficiently broad exposure of the bedding plane, however, nearly tangent sunlight may bring out a shadowy pattern standing in slight relief. Upon the well cracked surfaces the cracks average from 0.5 to 1.0 inch in width, the irregular polygons from 0.5 to 2.0 feet in diameter. The depth of the crack appears to be limited by the depth of the stratum, and is never traceable for more than 0.5 to 1.0 inch. Dimpled surfaces were occasionally observed, but the writer is not certain that the ones seen at this place were rain-prints. Rogers, however, observing other surfaces, reports rain-prints from this section. The definitely mud-cracked strata cease, on ascending through the formation, opposite the wagon bridge across the Schuylkill probably about three-fourths of the height from the bottom of the formation, and the rock becomes more of a sandy shale. Mud-cracked patterns are thought to be shadowed forth, however, in one or two places during the next couple of hundred feet. Here a lateral valley intervenes, and to the north of it occur the uppermost Mauch Chunk and the transition beds to the Pottsville. The outcrop of these transition beds, consisting of red shale, light colored sandstone, and conglomerate, while showing the sequence of the beds and giving good exposures of the conglomerate, do not exhibit the bedding planes of the shales.

It is thus to be concluded that at Pottsville, where the formation reaches its greatest thickness, at least two-thirds of it, including all the central portion, were formed under conditions which permitted frequent drying in the air of the successive strata previous to their burial.

Near the village of Dauphin, on the Susquehanna, 45 miles southwest of Pottsville, on the strike of the formation, H. D. Rogers noted the presence of mud-cracks exposed in a roadside quarry, and accompanies his description with an illustration. He states in 1858 that "frost and weather have long since defaced the surface, which, when it was freshly uncovered, many years ago, offered a striking example of the phenomenon."* This sentence of Rogers emphasizes an important point in connection with evidences of continental origin of argillaceous strata and one already partly stated earlier in this article—that in shale rocks such features as mud-cracks, especially where filling and matrix are alike, can usually only be well observed upon fresh exposures of the bedding planes. It is possible to study an entire section of natural outcrops of

* Geology of Pennsylvania, vol. ii, part ii, p. 831.

shales without having the attention called to the presence of mud-cracks, even though the formation may in reality abound in them.

The writer examined also the section from White Haven, on the Upper Lehigh river, to Wilkes Barre, but the exposures were old and those of shale not numerous, with the result that well defined mud-cracks were noted at only one place. This was in the *lower portion of the formation,* 3.5 miles north of White Haven, where the fresh waste rock from the excavation of a cellar had been thrown two years previously into the roadway. In this material numerous good examples of both mud-cracks and rain-prints were found. Slabs bearing rain-prints were also observed, however, on the road leading to the White Haven sanatorium in the *Upper* Mauch Chunk, as well as at this other locality.

These indications of exposure to the air during sedimentation were found from 15 to 18 miles north of the present southeasternmost outcrop at Mauch Chunk and in what is now on the strike of *the central portion of the basin of deposition.* That the basin was formerly much more extensive is shown by the fact that the Mauch Chunk formation reaches its greatest thickness in the region of the southern coal basin, but the material is fine grained and not strikingly different from that farther northwest. Considering its thickness of 3,000 feet, this outcrop must have been at least a score of miles, and perhaps several times that distance, from the southeastern margin of the original basin. There is nothing, in fact, save these marks of subaerial exposure to suggest the proximity of such a shore as has been frequently postulated in order to explain their presence. The results of these limited observations indicate that further detailed search would doubtless yield, on other sections, still more evidences of widespread mud-cracking.

The Pottsville and White Haven sections further supplement each other. At Pottsville the middle two-thirds of the Mauch Chunk were well displayed and showed that the argillaceous strata were habitually exposed to the air and well dried before being covered by the succeeding stratum of sand. At White Haven evidences of subaerial exposure were found in the lowest quarter and also in the uppermost quarter of the formation. If it be not unwarranted to consider the evidence of the one region as applying also to the other, it may consequently be stated that from the beginning to the end of the deposition of the Mauch Chunk in the region of the southern and middle anthracite coal basins there is inorganic evidence of a frequent exposure to the air following the laying down of the argillaceous strata. Naturally in only a small per cent of the beds would the evidence of such exposure be both preserved and exposed.

Organic evidences of subaerial exposure.—These may be divided into evidences furnished by the animal and vegetable kingdoms respectively. Of the first class the most famous are the tracks left by *Sauropus primævus* near Pottsville, mention of which enters into all text books, and which, at the time of their discovery by Mr Lea, in 1849, were the oldest known amphibian footprints. Rogers states that they were found about 700 feet below the top of the formation, and adds:

"About 1,500 feet lower in the formation the Geological Survey brought to light another species of footprints of much smaller dimensions; and soon afterward two other varieties, at a spot not far south of the West Branch gap in Sharp mountain. They are always at the incohering partings between easily separating beds of sandstone; and the indented surface is glazed with a fine slimy clay, such as retreating turbid water leaves behind it. The scaling off of this coating of clay soon obliterates the smaller footprints."*

The present writer found another imperfect impression in a mud-cracked stratum not far from the horizon of *Sauropus primævus.*

Supplementing this direct evidence of the presence of terrestrial life is the statement made by Rogers in 1858, and which still holds good, that the only marine fossils found within the formation are comprised within the thin wedge of the Greenbrier limestone, beginning at its edge in Cambria county and passing thence southwardly through Somerset county to Maryland.† Farther south, as well as in the Shenango shales of northwestern Pennsylvania, marine fossils of Chester forms have been found in strata which J. J. Stevenson regards as contemporaneous with the Upper Mauch Chunk.‡ Beside the footprints, the only evidences of animal life noted by the writer were worm tubes in the shales, crooked and rambling, filled with a soft and more lustrous material, distinguished from plant stalk impressions by the lack of straightness, and from roots by the lack of attached rootlets. In addition, there are occasionally other markings whose origins have not been positively identified. Rogers gives an example of one of these which he thinks may be the trail of a mollusk.§

The vegetable kingdom also furnishes its share of evidence, probably no less positive in its nature, if understood, but in regard to the proper interpretation of which it is more difficult to be assured. On these Rogers makes the following notes:

"The only organic remains ever met with in the Umbral red shale of our eastern coal fields are some rare impressions of a large plant-like form, dis-

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* Geology of Pennsylvania, vol. ii, part ii, 1856, p. 831.

† Ibid., p. 832.

‡ Notes upon the Mauch Chunk of Pennsylvania. American Geologist, vol. xxix, 1902, p. 248.

§ Geology of Pennsylvania, vol. ii, part ii, p. 832.

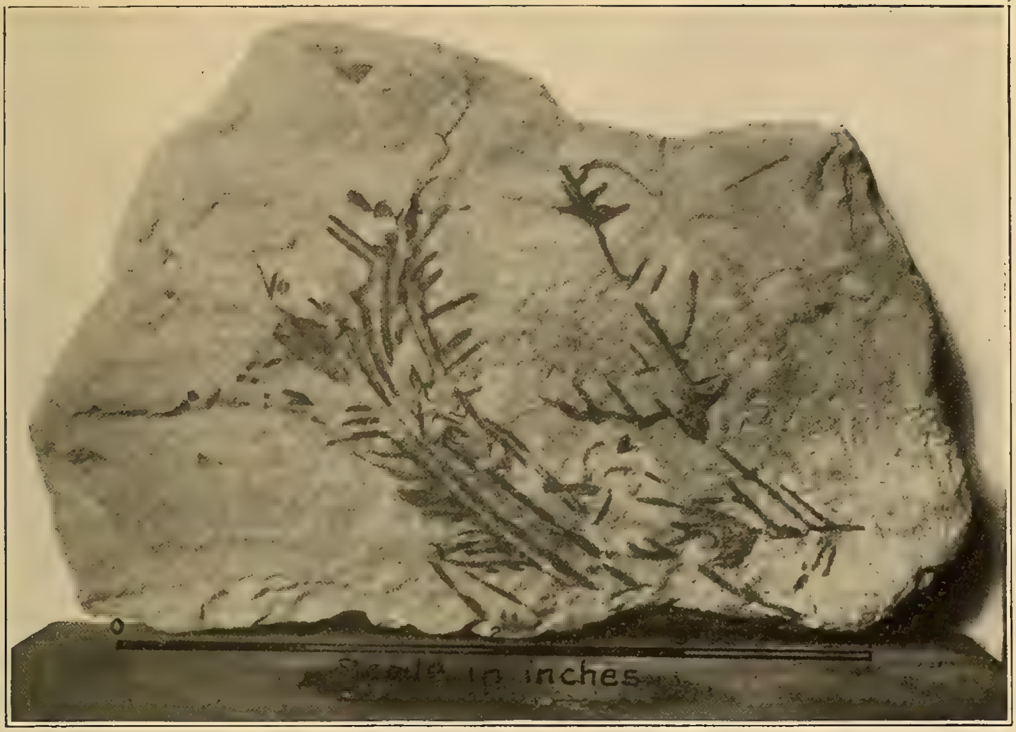

FIG. 1.—PLANT IMPRESSION IN UPPER MAUCH CHUNK SHALES, WHITE HAVEN, PENNSYLVANIA

Impression emphasized by India ink wash applied to photograph

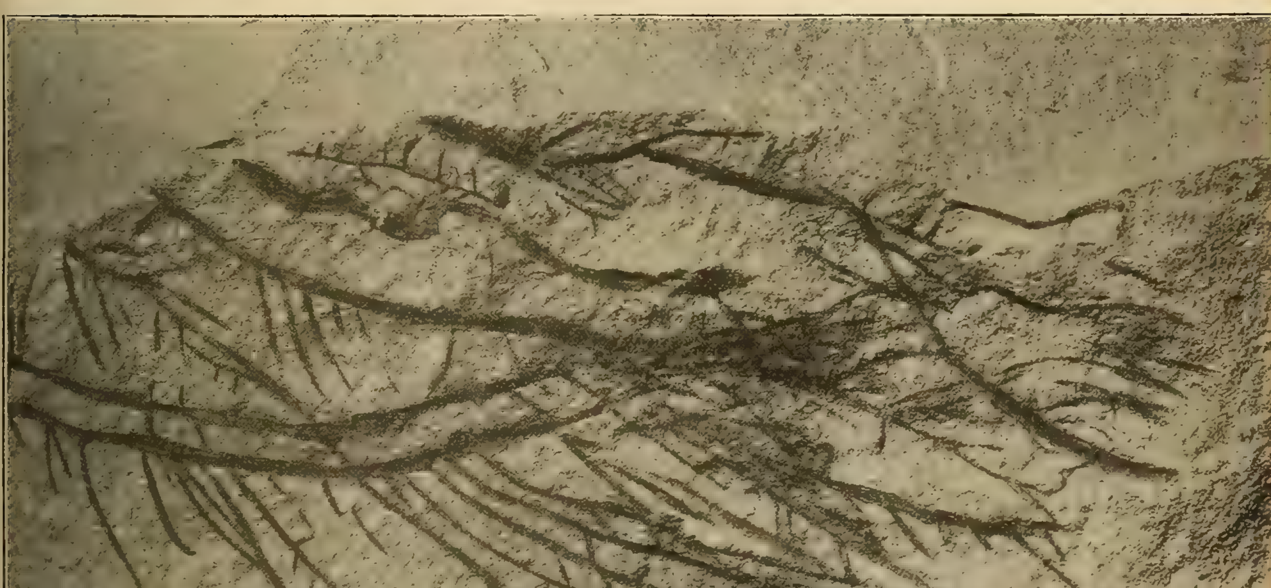

FIGURE 2.—PLANT IMPRESSION FROM MAUCH CHUNK FORMATION, POTTSVILLE, NEAR LOCALITY SHOWN IN PLATE 50

PLANT IMPRESSIONS IN MAUCH CHUNK SHALES

ROOT IMPRESSIONS IN SANDSTONE—UPPER MAUCH CHUNK SHALES

Entrance to White Haven Sanatorium, White Haven, Pennsylvania. The left-hand view is in place in a gently dipping sandstone. The right-hand view is on a loose slab, and original position is consequently unknown. Impressions emphasized for reproduction by India ink wash on photograph

covered by us in the valley immediately south of Sharp mountain, at Pottsville, and in a few corresponding localities. This imprint upon the red sandstone has often the aspect of a large, fleshy leaf, curiously corrugated, as if it had been crumpled, while in a flaccid state, by compression beneath a newly deposited load of sediment. Each leaf-like portion exhibits a raised rib like an obscure rachis, but in other respects it bears a general likeness to some tribes of the algæ, or sea-weeds. Professor Balfour has kindly favored me with a note upon it.

"We sometimes find associated with this feather-like plant another marking in the rock, which traverses the strata perpendicularly and branches downward like a root, and which, from its generally occurring in the same layers with the flattish, fucus-like impression, we may conjecture to have been its actual root. In one or two instances this root-like form has been seen to proceed from a large rudely spherical body of similar structure, impressed on the surface of the same layer of red sandstone which contained a quantity of the flatly expanded supposed sea-weed—a further evidence of their being related as the upper and lower parts of the same vegetable. The leaf-like portion is sometimes between 2 and 3 feet long and several inches wide, and the impressions regarded as its root are of the length of some inches."*

The present writer was fortunate in finding some well defined plant impressions at White Haven and also at Pottsville. Those on the bedding planes in the White Haven region were: *First,* fragments of slender reeds resembling thin grass stems and exhibiting joints; *second,* impressions of flattened, strap-like, coarser stems and leaves up to an inch in width and exhibiting suggestions of parallel venation; *third,* impressions of stems with close set spiny leafage, the spines not being over half an inch in length; an illustration of this type is shown in plate 51, figure 1; these may be portions of the feather-like plant noted by Rogers. In plate 51, figure 2, is shown an impression found on a loose block of sandstone at Pottsville, which on account of being developed in one plane is thought probably to be the subaerial rather than the subterranean portion of a plant. If this interpretation be correct, it is probably somewhat related in nature to the more thickly set spiny leafage shown in plate 51, figure 1; *fourth,* in sandstone strata the root-like impressions were found as described by Rogers, the roots branching downward into primary and secondary branches and giving rise to fine tendrils; but whereas Rogers found the root impressions of a length of some inches only, the present writer found them exposed for a depth of fully a foot, with indications of being at least twice that length (see plate 52).

Specimens, drawings, and photographs of these plant impressions were submitted to A. W. Evans, Eaton Professor of Botany, of Yale university, who kindly gave the following opinions:

* Ibid., p. 830.

First. The hollow, jointed, slender, reedy fragments suggest the equisetæ. The siliceous nature of their tissues is well known, and these are the only plant impressions in which any of the original substance remains, though the carbon has completely disappeared.

Second. The impressions of the flattened leaves suggest affinities with the cordaites.

Third. The spiny leafage resembles the lycopodiaceous plants. In none of these could Professor Evans see resemblances to the algæ with which he was familiar.

Fourth. The root markings suggest a plant which drew nourisment from the soil. The larger marine algæ, on the contrary, customarily are attached to stones by means of hold-fasts. The smaller marine algæ sometimes develop root-like hold-fasts where growing on muddy or sandy bottoms, but these in modern forms are always small and delicate.

Plant remains, for the purpose of the present paper, are not of high value unless there is evidence of burial in the place of growth, as in the case of the root impressions, but it is seen that, in as far as they go, they are suggestive of a land origin. The manner of preserval of the remains is, however, most suggestive. No carbon is in any case preserved; neither has the loss of carbon decolorized the contiguous shale, as is often the case in carbonaceous strata. On the contrary, the plant impressions are simply smooth lustrous patterns, marked out in the duller background of red shale, but of precisely the same color value. This implies complete oxidation of the carbon by free oxygen, and not by oxygen from the ferric oxide. It occurred, therefore, before the deep burial of the accumulating strata, but after the superficial burial of the plant fragments.

Part II. Inferred Conditions of Origin

PREVIOUS OPINIONS

Rogers ascribed to the Mauch Chunk an origin in a shallow sea,

"contiguous to agitated coasts swept by turbid currents, a sea too foul with poisonous sediments to permit the presence of the usual marine animals; and the abundance of ripple-marks, sun-cracks, and the specks attributed to rain, and called rain-spots, confirm the impression of the nearness of the land by giving proof that the layers, while yet freshly deposited, were frequently laid naked to the atmosphere."*

Rogers is thus seen to have framed an explanation which reconciled the universal opinion of his time, that sedimentation was essentially a marine or lacustrine phenomenon, with his own observations indicating

* Geology of Pennsylvania, vol. ii, part ii, 1858, p. 794.

a frequent exposure to the atmosphere. One weakness, among others, of the resulting hypothesis lies of course in the contradiction of modern with geological evidence, which shows that abundant muddy sediments are favorite haunts for certain kinds of marine organisms.

Lesley states, in summing up his conclusions on the origin of the Mauch Chunk after a lifetime of study on the Paleozoic formations of Pennsylvania, that—

"It is astonishing to see the great green and gray cross-bedded sandstone of the Pocono age immediately followed by an equally great thickness of fine red and reddish muds deposited in layers sometimes as thin as paper, sometimes mixed with fine red sand, and showing so extreme a shallowness of the water that the foot-tracks of lizards, rain-drops, and shrinkage cracks produced by the heat of the sun have been retained between the layers. This shallowing of the sea along what was undoubtedly a broad and low-lying shore receives additional evidence from the occurrence of several small coal beds and several small layers of iron ore at the top of the formation, the coal layers sometimes being consolidated into a thin, workable coal bed, and the series of thin, solid or nodular iron ore layers turning in places into solid beds of carbonate of iron 4 feet thick, as at Ralston, Queens run, etc., or multiplied and made economically valuable for furnace use, as on the west side of Chestnut ridge, in Fayette county.

"The surprise of the field geologist is renewed by observing this great red shale formation immediately succeeded by the great basal conglomerate (Pottsville No. XII) of the lower productive coal measures. . . . No disturbance from folding or uplifting of the red shale before the laying down or coming in of the conglomerate is anywhere visible, and I can suggest, after many years of study, no explanation of the phenomenon. Others may be more successful; but up to the present moment I look upon this as one of the many unsolved problems in our geology, waiting not so much for more facts as for a shrewder and more fortunate suggestion. I think no one can doubt that the red shale was deposited on a broad shore-bordered lowland near the sealevel, and in regions of its wide extent occupied by marshes, pools, and lagoons on which the first true coal vegetation began to grow, and that in connection with this vegetation considerable deposits of carbonate of iron, or of limonite afterwards carbonized, were formed."*

It is seen from the above that Lesley recognizes the one problem, that offered by the contrast of the Mauch Chunk with the preceding and succeeding formations, and also the second problem, that given by the evidences of shallow water and occasional exposure to the atmosphere. While not professing to understand it, he states the conclusion that "the red shale was deposited on a broad shore-bordered lowland near the sealevel." Thus he practically reaches a belief in its origin as a river deposit marginal to the sea, but without specifically calling it a

* Second Geological Survey of Pennsylvania. Summary, vol. iii, part i, 1895, pp. 1806-1807.

subaerial delta formation. His quandary in this respect is clearly due to his inability to reconcile his logical conclusion from the facts with the still prevailing dictum that sedimentation implied the presence of permanent bodies of water, the only exceptions of consequence believed in being the exposure through tidal ebb of accumulating mud-flats marginal to the seas.

Other geologists, not having had occasion to study the formation with the same detail as Rogers and Lesley, have apparently been less impressed with the evidences of subaerial exposure, so that the description of Rogers, now half a century old, is still the most detailed, and probably but few geologists are aware of the extent of these evidences.

The belief that all the Mauch Chunk sediments were of marine or littoral origin has been the only interpretation definitely expressed in the literature up to 1906. To mention the opinion of the two living geologists most widely acquainted with the formation: Willis, in his paper on the physical interpretation of all the Paleozoic sediments of the Appalachian basin, states that the Mauch Chunk "represents a height of land which was elevated, eroded, and distributed in the Carboniferous sea," and that in the following Pottsville times "the marked contrast in the sediments is significant of a change in depth and slope of the sea bottom. Tide flats of the Mauch Chunk epoch were submerged, and their practically level surface was replaced by one having a decided seaward inclination."*

J. J. Stevenson, in his summary discussion of the Lower Carboniferous, also speaks of the limits of the sediments as indicating the limits of the water body, and states that "at the east one finds evidence of continued lowering of the mainland and of continued advance of the sea upon a low shoreline."†

In 1906 Grabau published in a valuable paper a broad discussion, which contains, so far as the writer is aware, the first definite statement as to the fluviatile and non-marine origin of the Mauch Chunk shales.‡ This conclusion in regard to the Mauch Chunk is drawn, however, without detailed argument, but two pages being given to this formation, thus leaving room for the present paper. His opinion appears to be ultimately founded upon the growing appreciation by geologists of the importance of fluviatile formations in the stratigraphic column, and from the absence throughout the greater portions of the Pocono and Mauch Chunk formations of direct evidence of marine origin.

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* Paleozoic Appalachia. Maryland Geological Survey, vol. iv, 1902, pp. 66, 69.

† Lower Carboniferous of the Appalachian basin. Bull. Geol. Soc. Am., vol. 14, 1903, pp. 94, 95.

‡ Types of sedimentary overlap. Bull. Geol. Soc. Am., vol. 17, 1906, pp. 632-634.

The particular reasons advanced for the conclusions are based on:

First. The general absence of marine fossils, especially in the eastern outcrops (page 630), the presence of a 1-foot seam of coal 80 feet above the base of the Pocono in Lycoming county (page 631), and, in the Mauch Chunk, "the ripple-marks, sun-cracks, rain-drop impressions, and footprints of vertebrates—all signs of floodplain deposits" (page 633).

Second. The progressive overlapping westward of the Pocono and upper Mauch Chunk.

While these facts are undoubtedly of great significance, they are suggestive rather than conclusive and need support by detailed observations and discussions, as may be shown:

First. Sandstones and conglomerates are frequently barren of fossils, whether they be continental or marine. Marine fossils are found in certain shaly layers of the Pocono in Garrett county, Maryland, and in Huntington and Bedford counties, Pennsylvania, as noted by Grabau. No characteristic distinction is stated between the sandstones which are surely marine and those which are surely continental, the increased coarseness on the eastern side being noted, but greater coarseness toward the source of supply is true of both marine and fluviatile detritus. The presence of marine fossils in one place or of a coal bed in another is not evidence that any great part of the contiguous strata are either marine or continental, since in land-delta and shallow-sea deposits a widely fluctuating strand line is to be expected on account of the very flat profile of both the land surface and sea bottom. Finally, *so far as geological literature is concerned,* ripple-marks, sun-cracks, rain-drop impressions, and footprints of vertebrates, spoken of by Grabau as "all signs of floodplain deposits," are rated as more characteristic of tidal flats than of floodplains.

Second. Transgressive overlap toward the source of the sedimentary material is taken by Grabau as positive evidence of the presence of an invading sea (page 570), and progressive overlap of beds of shale or sandstone barren of marine fossils *away from the source of supply* is considered as still more positive evidence of fluviatile and terrestrial deposition of the sedimentary beds in question (pages 635, 636).

While the present writer is in general agreement with the conclusions in regard to the particular formations cited, yet he does not believe in the universality of these principles without qualification, or that they alone will suffice to prove the marine or non-marine deposition of shales and sandstones in general. On the contrary, it would seem that, applied

without other considerations, they might sometimes lead into considerable errors of interpretation.

INFERENCES AS TO GEOGRAPHIC CONDITIONS OF ORIGIN

Floodplain origin of the Mauch Chunk.—Either mud-cracks, rain-prints, footprints, or impressions of roots *in situ* were found from the bottom to the top of the formation in the eastern outcrops contiguous to the southern and middle anthracite coal fields, the region of its maximum thickness. They were also found to occur from the northeasternmost limit, on the Lehigh river, to the southwesternmost limit, at Dauphin, on the Susquehanna.

The significance of such a widespread distribution of the marks of subaerial exposure has been fully discussed by the writer elsewhere.* It seems unnecessary to repeat the argument, and it need only be said that reasons were shown for considering that such evidences pointed to a continental and more particularly to a fluviatile origin. It is to be concluded, therefore, that the Mauch Chunk sediments were brought by the flood waters of one or more rivers and spread over the river plains in times of flood. In this region of greatest subsidence and accumulation and far from the margins of the basin the sea seems to have at no time extended, but to have been kept out by the abundance of the river sediment and the consequent rapidity of the upbuilding, keeping pace with subsidence.

Relations of land and sea.—The evidence has been given in the first part showing the marked thinning out of the Mauch Chunk around the northern half of the northern anthracite field. It has also been seen that but an insignificant thickness of strata represents the formation through the northern tier of counties in Pennsylvania, and that it is entirely probable, as held by Rogers, that it was never deposited in greater thickness in that region. The lower portion, however, is represented in the southwestern quarter of the state by the northern edge of the Greenbrier limestone, which thickens greatly on passing west and south. Under the Greenbrier limestone in Pennsylvania lies a thin horizon of red shales, 140 feet thick under the Broad Top coal field, 50 feet thick at the most southwestern outcrop in the state. It is not known, however, that these shales are continental and they may well be marine, since a fairly wide zone of marine terrigenous deposits may skirt the land.

From these relations it is seen that during earlier Mauch Chunk time

* Mud-cracks as a criterion of continental sedimentation. Journal of Geology, vol. 14, 1906, pp. 524-568.

a shallow sea progressively invaded Pennsylvania from the southwest and reached as far north as central Pennsylvania, but it did not at any time reach as far northeast as Pottsville.

Following this main incursion came a period of land extension. Ferruginous sands and muds were now deposited over almost the entire state of Pennsylvania. Along Chestnut ridge, in southwestern Pennsylvania, Rogers first noted the presence of two beds of coal imbedded in the shales immediately under the Pottsville conglomerate.* The upper shales are characterized in western Pennsylvania by the presence of iron ore also. Of this ore Rogers states:

"The chemical nature and geological relations are very similar to those of the carbonate of iron of the coal strata, and the conditions under which it originated were obviously very nearly identical with those which produced that variety. The Umbral (Mauch Chunk) shales contain, especially in their southwest outcrops, as in Somerset and Fayette counties, a species of ore identical with the ordinary compact or earthy carbonate of the Coal Measures. This latter kind belongs to a small subordinate group of coal-bearing rocks, which, in the districts mentioned, underlie the true Seral (Pottsville) conglomerate, or constitute its lowest member, indicating a gradual transition from the Umbral series."†

Fuller, in the Elkland-Tioga folio, dealing with a quadrangle on the northern boundary of Pennsylvania, gives a section of the Mauch Chunk, which is here only a little over 100 feet thick. In the upper portion is noted the occurrence of 4 feet of pure bog iron ore. Many iron ores are concentrated by underground waters, for which reason no mention has been made of the ores at the very base of the Mauch Chunk shales in Huntington county. But these upper ores, similar to those of the coal strata and associated in some places with coal, in another locality spoken of as a "pure bog iron ore," may be taken as strong evidence of river-swamp conditions at the time of origin of the strata.

As noted in the description of the relations of the Mauch Chunk to the other formations, there is thought to be a considerable erosion interval in western Pennsylvania separating the Mauch Chunk from the Pottsville, representing the time of deposition of the Lower Pottsville and possibly some of the Upper Mauch Chunk of eastern Pennsylvania.

It would seem, therefore, that while in eastern Pennsylvania subsidence and river building were continuous, in western Pennsylvania, from the time of the formation of the Greenbrier limestone, the crust was practically stationary or slightly uplifted, with the result that the shallow sea was filled with mud and finally changed by river outbuilding into a broad

* Geology of Pennsylvania, vol. ii, part i, 1858, p. 472.
† Ibid., vol. ii, part ii, p. 734.

delta surface which in regions farthest removed from the sources of sediment was occasionally in a swampy condition. Finally moderate uplift or change in river gradients occurred, with the result that river building was changed to river erosion, and the land surface is at this epoch, from the evidence of erosion, known to have extended over much of the Mississippi valley.

Relations of the delta plain to regions of erosion.—The material which built up the Mauch Chunk foreland plain consisted of clay and loamy clay and some loamy sand, transformed now into shale, sandy shale, and argillaceous sandstone. Near the top appear occasional beds of conglomerate transitional to the Pottsville. The character of the Mauch Chunk is much alike from the northeastern to the southwestern limits of the southern anthracite basin, a distance of 80 miles, and changes but slowly in passing northwest, away from the sources of supply. This approach to uniformity of composition over a broad area is characteristic of the delta plains of large river systems, where the material has already traveled the greater part of its distance before reaching the upper limits of the delta. It implies, therefore, the existence of a long intermediate graded portion of the river course between the region of the headwaters supplying the material and the region of its deposition. The rate of supply of the sediment was sufficient to continually bar the sea from the anthracite regions, notwithstanding the combined epeirogenic and geosynclinal subsidences of Lower Mauch Chunk times. In this way was built up a deposit reaching a maximum thickness of 3,000 feet and of which the remaining areas constitute but a remnant of the original volume. The fineness and uniformity of the material imply leisurely currents; and that the accumulation was slow is indicated by the thickness of the limestones laid down during the same interval in the Mississippian sea. That the erosion of this material did not transform the topographic character in the regions of erosion is suggested by the approximation to uniformity in the material making up the whole formation, the greatest mass of pure shales being found in the lower part of the formation. The volume of the land above baselevel which supplied the material for the Mauch Chunk was therefore large in comparison with the volume of the formation, unless, indeed, a slow rise *pari passu* of the regions of erosion be postulated corresponding to the amount eroded.

Character of the delta surface.—The surface of the Mauch Chunk delta in all of eastern and central Pennsylvania seems to have possessed a fair grade to the westward, sufficient to prevent the development of broad swamp areas, since in those regions decolorized shales are practically absent. The grade which this indicates varies with the climate, since in

one which is hot and dry the intense evaporation will speedily dry up flat lands which otherwise would remain as swamp areas. Observation of present deltas indicates, however, that even in arid climates the portion marginal to the sea is occupied by permanent lagoons in which, under conditions of high aridity, are deposited gypsum and salt. In climates marked merely by dry seasons, however, such marginal swamp areas may hold fresh or brackish waters and be the seat of a dense swamp vegetation. Evidences of a state approaching this is seen in the Mauch Chunk shales in their outcrop beyond the Alleghany escarpment in western and northern Pennsylvania, where, as noted previously, thin beds of coal sparingly occur and considerable deposits of earthy carbonate of iron similar to that of the Coal Measures. Taking for analogy the grade of the loaded rivers flowing east from the Rocky mountains through the semiarid to subhumid climatic belts, it seems probable that in the region of the anthracite basins the river grades were certainly over 2 feet per mile, possibly over 5 feet per mile, flattening out in the more distal portions of the river system.

The profile of a graded river depends upon the fineness of load and its ratio to the water. This is partly dependent, therefore, upon the climate as well as the lithology and topography of the regions of erosion. The climatic reasons for comparing the stream grades with those of the rivers flowing east from the Rockies are more fully developed in the following section.

INFERENCES AS TO CLIMATIC CONDITIONS

Introductory statement.—Climate exercises a controlling influence upon the characteristics of delta deposits, as may be readily seen by comparing the delta of the Indus, largely a barren surface of drifting sands, with that of the Amazon, swampy and mantled with an impenetrable forest; or that of the Yukon, covered with a mat of cryptogamic and gymnospermous vegetation, giving rise to widespread accumulations of peat. A full discussion of the *"Relations of climate to terrestrial deposits"* led so far afield that the subject was separated from the present paper and is to be published under that title elsewhere.* All present arguments as to the climatic inferences from the nature of a continental formation are therefore much abridged.

Chemical and structural evidences as to climate.—In northern and western Pennsylvania thin coal beds and iron carbonate occur in the Upper Mauch Chunk shales, while in eastern Pennsylvania horizons of conglomerate give a character transitional to the Pottsville. Although it is seen that the coal seams and iron ore are deposited where the river

* See abstract, Proc. Bull. Geol. Soc. Am., vol. 18, 1906.

grades were flattest and swamp conditions most favored, yet such deposits only occur in the upper shales. These relations suggest that the later part of the Mauch Chunk epoch was marked by a series of climatic oscillations toward the conditions prevailing in Pottsville times—conditions which there are reasons shown elsewhere for believing were characterized by a heavier rainfall and probably cooler climate. On the other hand, gypsum and salt are not known to be present in noticeable amounts in any part of the Mauch Chunk, although much gypsum and considerable salt are present in the shales and argillaceous limestones of the Michigan series of Michigan, which is probably to be correlated with the Lower Mauch Chunk. Thus the indications point toward the climate of this epoch in Pennsylvania being of a semiarid character, seasonal rains being sufficient in amount, in conjunction with the discharge of large rivers, to prevent the precipitation of salt or gypsum on the marginal flats facing the Appalachian gulf of the Mississippian sea, but at times permitting such in the more isolated Michigan basin.

The semiaridity of a climate with a slight or a seasonal rainfall is accentuated by high temperature. That the climates of sub-Carboniferous times were marked at least in part by warmth is indicated by the fossil plants and corals of so northerly a land as Spitzbergen.

The semiaridity of the Mauch Chunk climate of Pennsylvania is further indicated by a number of chemical and textural features characteristic of the formation in the region of the anthracite basins. Here an appreciable amount of feldspar grains intermingled with the quartz grains of the sandstones are detected by the microscope and calcite is fairly abundant in the matrix. This abundance is expressed megascopically on many horizons by the development of concretionary nodules usually in certain stratigraphic planes, the close association with mud-cracked strata in at least one instance indicating that they are not, however, the calcareous deposits transitional to an open sea. In the fine-grained and shaly sandstones an examination by the microscope shows that both muscovite and calcite are conspicuously present. Hematite, as previously stated, is diffused through both shales and sandstones, though naturally more abundant in the former.

The interpretation of these facts would appear to be as follows:

The feldspar present after prolonged transportation indicates a notable degree of physical as contrasted to chemical weathering in the regions of erosion. The presence of the uniformly diffused iron oxide points to a lack of leaching by organic acids either at the headwaters or upon the drained portions of the floodplain surface. The presence of the calcite in slight amount is characteristic of all floodplains, but is only found to

the extent here present in those of semiarid climates. In fact, as previously noted, the calcite throughout much of the Mauch Chunk is so abundant as to form concretionary bands analogous to the kankar of the hot and semiarid portions of the Indo-Gangetic plains. That seasonal drying and consequent aeration of the soil took place to the greatest depth of root penetration is indicated by the universal elimination of organic matter by oxidation without accompanying reduction of the intermingled iron oxide to the ferrous state, the plant impressions being always of the same color as the surrounding rock. The oxygen used up in the process was consequently atmospheric oxygen, and the blue and gray muds of swamps and river bottoms in our own climate testify to the difficulty of free oxidation of organic matter in a water-saturated soil where the surface remains moist, even though there may be no superficial standing water.

These conclusions are further supplemented by the presence of many mud-cracked strata, since these are prominent features of modern floodplain deposits of argillaceous character in arid and semiarid climates. They are not entirely absent from the clays of floodplains under somewhat humid climates, but are there much restricted in development, owing to the mat of vegetation and the greater ratio of rainfall to evaporation. The details of the mud-cracks as observed in the Mauch Chunk at Pottsville further emphasize the conclusion, since they seem to have been filled during the dry seasons by wind-drifted sands—a phenomenon which may be observed today in certain arid and semiarid regions.

Before closing this topic of the climatic inferences it seems desirable to call attention to the absence of notable bottom channeling exhibited by the sandstone strata, the contacts of the sandstone with the underlying shale being straight and conformable within the limits of a single exposure. Such a characteristic at first sight seems incompatible with the idea of stream channels wandering across the surface of a floodplain.

It is to be noted, however, that many floodplain deposits of the western United States and of other regions show in section well developed stratification with but little marked bellying downward of the sandstone strata into the shale. Such structures are occasionally noted in the coal fields, where Carboniferous river channels have cut through the coal beds, but those familiar with the coal mines know how unusual is this feature and how rarely nature would expose it at the surface in normal outcrop. Yet it seems certain that in many coal fields at least the greater portion of the strata are of continental origin. It would appear, therefore, that until the details of the sandstone strata are worked out with completeness the absence of such relations visibly exposed must not weigh against a hypothesis of subaerial origin.

A possible explanation of the phenomenon in some instances may be as follows: Rivers which over a portion of their course are aggrading streams are commonly only such for a portion of the year. During the balance of the year the water is less in quantity, is underloaded, therefore is degrading, and flows within channels which carry the sediment through to the sea. The *size of the channel* is doubtless determined to some extent by *the volume of the stream* during *its season of degradation.* Where the discharge is always large, as in the Mississippi system, large permanent channels through the floodplain will exist; where small, as in the Platte, the result may be a shallow channel holding a braided river, which, to use a popular aphorism, is a mile wide and a foot deep. Where there is no water except during cloudbursts, and every flood is overloaded with debris, sheetflood erosion and deposition, as described by McGee, may be the consequence.*

In a region of arid or semiarid climate, therefore, where the rainfall is highly concentrated and the streams are either dry or overflowing, there would seem to be a favorable case for the development of interlaminated sand and clay deposits without the occurrence of massive sandstones possessing an irregular bottom and cross-bedded structure. That the explanation may not be so simple as the above is indicated, however, by the deep scouring of such streams as the Platte, which in times of flood may "rise downward" as much as 90 feet, and which by the wanderings of the channel must rework the thin-bedded deposits of its floodplain and presumably leave sand in the filled-up places. Over a broad delta, however, such deep scouring would not appear to be called for, since there the flood waters cover a large part of the country and move leisurely seaward, relieving the channels from carrying an undue proportion of the water. Under such conditions, also, the channels are insignificant in area in comparison with the floodplain, and consequently in the lateral wanderings of the channels accompanying the upbuilding of the floodplain but a small per cent of the deposit would represent the fillings of the abandoned courses of the larger distributaries.

Organic evidences as to climate.—At times as early as the Middle Devonian an arboreal vegetation existed where the climate was suitable. In the sub-Carboniferous, and presumably earlier, the vegetable kingdom, then as now, lived in certain groups adapted each to a different environment. These plant societies at that time, however, were made up entirely of gymnospermous and cryptogamic forms, plants which have since been driven into the background by the more successful class of angiosperms. While it would be unsafe to argue too rigidly that the identical conditions

* Bull. Geol. Soc. Am., vol. 8, 1897, pp. 87-112.

which today favor arboreal or herbaceous forms held true for those of the sub-Carboniferous, yet in a general way this must be true, since arboreal forms are developed by competition for sunlight among those plants whose roots are able to penetrate deeply for groundwater and whose superstructure does not die each year. The present grasses, on the contrary, and by analogy the grass-like forms of earlier floras, are favored by light and fairly frequent rains during a growing season, which may be brief and after which the exposed portion of the plant dies. The presence of deeper-seated stores of groundwater is of no moment to the prairie types of vegetation. It is these relations of rainfall and groundwater which, as Schimper points out, determine the distribution of woodland and grassland. Over many regions the competition between the two types of vegetation is, however, very close, resulting in a mixed or park-like formation. In Paleozoic times it may very possibly have been true that specialized drought-resisting arboreal forms had not yet come into existence, and the climatic relationships of herbaceous and arboreal societies may have been then more sharply drawn than in modern vegetation. At least, evolutionary progress would be in the direction of an obscuring of such relationships.

Turning to the vegetal evidences found in the Mauch Chunk shales and which have been described previously, it was noted that, although the impressions of an herbaceous vegetation were not uncommon, no impressions of logs, such as are so common in the overlying Pottsville, have ever been observed. The various markings, furthermore, show small forms, such as could well be produced in a single growing season. The downward striking roots point to a poverty in superficial moisture, and the absence of an arboreal vegetation suggests a deficiency during the growing season of more deep-seated waters. Even in arid climates, if the streams flow during the whole year or the groundwater is within the reach of the roots of trees, the streams are fringed with shrubs and trees.

The evidences of the vegetal impressions point, therefore, toward a climate such that in the lower portions of the river courses the streams flowed only during a part of the year. During another part of the year the surface dried up and the groundwater sank to depths where the roots of the early trees could not penetrate. These evidences therefore point to an arid or semiarid climate.

The amphibian footprints might be thought to weigh against this conclusion, but the force of such a criticism may be weakened by a consideration of the following possibilities: It is to be noted that the present dipnoi, *ceratodus* and *protopterus*, have only escaped extinction in regions with a marked dry season, the *ceratodus* living in two Australian rivers which are in winter reduced to pools, the *protopterus* living in certain

African rivers which go completely dry. It would seem that such a seasonal dryness must have stimulated greatly the evolution of terrestrial and air-breathing types of animals from those which could live only in fresh waters. Having once gained supremacy through the greater activity possible from air breathing, a period of expansive evolution would naturally set in. This would be marked on the one hand by the passage of the amphibians back to the regions more generously watered, which they would come to dominate until the still more powerful aquatic reptiles should in turn dispossess them.

On the other hand, in perhaps a closely following time, a progressive evolution from these first air-breathers, themselves brought forth by the alternation of wet and dry seasons, might be expected to lead still further to groups wholly independent of a life in the water, and thus rather quickly give rise to the primitive reptilian and mammalian stems. Considered in this light, the wide development of climates with dry seasons such as seem to have characterized the Upper Devonian, and still more so the Mauch Chunk epochs, may have had vital importance in stimulating the terrestrial evolution of the previously aquatic vertebrates. In support of this hypothesis may be mentioned the distinctness of the reptilian and early mammalian stems, the *Diapsida* and *Synapsida,* even in the Permian, indicating that the mammals did not arise from the reptiles after a considerable evolution in the latter, but that they arose possibly independently from amphibian ancestors at least far down in the Carboniferous age. The type forms of the amphibian and higher groups, being adapted to somewhat different environments, would not enter into competition until the higher groups had somewhat expanded and given rise to aquatic adaptations.

Furthermore, it is to be noted that under such a hypothesis no amphibian bones which have been or may be found are likely to be directly ancestral to reptiles or mammals, since floodplain deposits in climates with alternate wet and dry seasons are peculiarly unfavorable for the preservation of animal remains. There is thus, possibly from the nature of things, a permanent break in the record of the evolution of the vertebrates.

These views are avowedly hypothetical, but they suggest that in sub-Carboniferous times the amphibians may have been adapted to semiarid conditions as well as to those more humid, and therefore the presence of their footprints in the Mauch Chunk strata argues only against high aridity.

Conclusions and comparisons.—We may draw, in conclusion, a general view of the seasonal changes taking place over the Mauch Chunk fore-

land plain. The various lines of evidence strongly suggest that during the greater part of the year, when not in flood, the surface of the delta was dry and the channels greatly diminished, but doubtless offering sufficient water for the preservation of the amphibian life. With the beginning of seasonal rains the shallow channels would speedily become full to overflowing and the waters spread over large portions of the delta surface in a shallow and braided flood. Following the retreat of the flood waters, an herbiverous vegetation would spring, as by magic, from the loamy soil, only to wither with the advancing dryness. The modern climates suggested by this description are, for one example, the semiarid belts of winter rains, as illustrated in Spain, Italy, and Greece. Another example is given by the monsoon climate of the upper Punjab, a region which receives about half of its annual rainfall during July and August, and during two-thirds of the year, from September to May, is a barren desert. The shrunken rivers then fill but a fraction of their beds and leave the remaining portions as plains of loose sand. This is raised by the strong winds, giving dust storms so thick as to prevent objects a few yards distant from being seen and mantling with eolian sands the dried-out loams and clays of the floodplain.

The comparison with the upper Punjab may be happily made in regard to the geographic characters also, since here is an alluvial plain stretching away from the Himalayas, approximately 200 miles in width at Delhi, and in the line of the Indus river reaching more than 700 miles through a highly arid region to the Indian ocean.

The Himalayas, uplifted after the close of the Eocene and receiving renewed uplifts from time to time, correspond to that vanished generation of the older Appalachians which arose in Upper Devonian times and during that and the following eras wasted away, a portion of its eroded foundations remaining in New England still above the sea.

The debris of the Himalayas has poured for half of Tertiary and all of Quaternary time into and beyond the great Indo-Gangetic geosyncline. That portion of the waste of the older Appalachians which was shed westward was swept into and sometimes beyond a similarly placed geosyncline, that of the Appalachian basin. The sands and muds of the Devonian alone which were trapped in this axis of subsidence have been computed by Bailey Willis to be equal in volume to the Sierra Nevada.*

Medlicott and Blanford in 1879 pointed out the fluviatile character of the later Tertiary strata and state that from early Tertiary times the sea has been excluded from the sub-Himalayan region,† where sediments

* Paleozoic Appalachia. Maryland Geological Survey, vol. 2, 1902, p. 62.
† A Manual of the Geology of India, pp. 525-526.

accumulated as a foreland plain. The Miocene sediments constituting the Siwalik formation alone reach a thickness in northwest India of 14,000 feet and suggest the competence of the sedimentation to exclude the sea. A like consideration of the evidence furnished by the Upper Devonian and Carboniferous sediments of Pennsylvania would seem to show that the generation of the older Appalachians then existing was equally competent to continuously exclude the sea from the eastern side of the geosyncline; that it certainly did so during the Mauch Chunk epoch it has been sought to demonstrate in the present paper.

There is abundant evidence, however, that the sea has at times occupied portions of the lower plains of the Indus during the later Tertiary, corresponding again to the evidence of a marine invasion of southern Pennsylvania during Lower Mauch Chunk times. The present broadly extended character of the Indus delta may then be compared with that broad development of land which seems to have occurred at the close of the Mauch Chunk.

These comparisons, while not intended to convey the idea that the Appalachians were ever of Himalayan magnitude, are suggestive of a more massive range of mountains and a wider land area to the eastward of the Pennsylvanian geosyncline than is customarily thought of as existing in Upper Devonian and Carboniferous times. Such a larger view is believed, however, by the writer to be in the direction of the truth.

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ASYMMETRIC DIFFERENTIATION IN A BATHYLITH OF ADIRONDACK SYENITE *

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INTRODUCTION

Of late years much evidence has accumulated to the effect that, under deep-seated conditions of igneous intrusion, not only is contact action widespread and on a large scale, but also that rock injection and rock assimilation are equally, or even more, pronounced. During the field work of the special committee on the correlation of the pre-Cambrian rocks of the Adirondack mountains, the original Laurentian area and of eastern Ontario, it was noteworthy that in both areas visited such phenomena were prominently to the fore. This paper deals with one of the specific instances examined by the committee, an asymmetric bathylith of syenite occurring in the mid-Adirondack region, whose

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asymmetry is thought to be owing to incorporation and assimilation of material from the bordering rocks.

General Description

The syenite rock in question is a common one in the Precambric area of northern New York, occurring in both large and small masses, in bathyliths and stocks, in dikes and sills. It is a member of the series of great intrusive bodies which invaded the region in pre-Cambrian time, and which solidified far below the surface, and is younger than the Grenville sediments and the Laurentian granite-gueisses of the district. Of the post-Laurentian intrusives it was the second in order of appearance, being younger than the anorthosite. As the above form the bulk of the Precambrian, it follows that the usual contacts of the syenite are those in intrusion. The rock is usually gneissoid, the smaller masses especially being thoroughly so, and so stretched and interleaved with other gneisses that the relations are much disguised. The especial mass under consideration is one of the most extensive, is adjoined by and shows contacts against two of the three great groups of older rocks, and the metamorphism is not sufficiently pronounced to obscure its relations to them. It therefore furnishes a very satisfactory sample for the study of these relations. Its main disadvantage is that it lies in a forested region, in which outcrops are not as abundant nor as satisfactory as could be wished and in which getting about is slow and laborious work.

This bathylith is situated near the central part of the woods, in the district centering about Big Tupper lake, and its main portion lies within the limits of the Long Lake topographic sheet, though running well into the Tupper Lake quadrangle, next west. It is of rudely elliptical shape, with a minor axis of about 8 and a major axis of from 12 to 15 miles; hence with an area of some 75 square miles as cut by the present erosion surface. On the north and east it is adjoined by anorthosite and on the south and west by Laurentian granite-gneiss containing much included amphibolite. Against both these it shows irruptive contacts, it incloses numerous fragments of them, and it sends out abundant dikes into them.

The normal Syenite

When fresh this is a green to grayish green rock, which experiences rapid color change upon exposure to the air, becoming first a deeper green, then more slowly passing to a yellow brown, and finally to a deeper rusty brown.* The color change does not at all affect the freshness of the rock as seen in thin-section.

* R. A. Daly: Bull. no. 209, U. S. Geological Survey, pp. 51-53.

The rock is a feldspathic one, averaging 75 per cent of this mineral, which is chiefly microperthite, although a small amount of oligoclase is always present in addition. Pyroxenes are next in importance, both augite and bronzite (or hypersthene) being present and exhibiting characteristic intergrowths. Quartz and magnetite are always present, hornblende often, and zircon, apatite, biotite, titanite, garnet, pyrite, and allanite are more or less frequent accessories. The rock is essentially a feldspar-pyroxene combination, with accessory quartz and magnetite, the feldspar being orthoclase in part and plagioclase (albite to oligoclase) in part, in perthitic intergrowth.

It is mostly a quite even grained rock, having been rather thoroughly granulated during a time of general metamorphism in the region during the Precambrian. Occasional small feldspar augen remain nearly everywhere and in some areas become much coarser and more numerous. Though crushed, the normal rock is not especially foliated, owing to its mineralogy. In its general aspect it seems much more metamorphosed than does the older anorthosite, and this is thought to be due to an original finer grain and lack of the huge porphyritic crystals which characterize the anorthosite.

The basic Syenite

When followed from place to place the syenite proves to be a quite variable rock, becoming both more basic and more acidic than the normal. Both are peripheral changes in the main, though both occur locally within the general mass. The greater basicity is produced simply by increase in the amount of ferro-magnesian minerals, with corresponding decrease in the feldspar and quartz, the extreme phase being a dark colored, heavy, gabbroic looking rock in which the dark minerals substantially equal the feldspar in amount, though it still remains a microperthite-pyroxene rock. The plagioclase constituent of the microperthite is slightly more basic than in the normal rock, but only slightly. Some hornblende is usually present and garnet often appears, occurring as a corrosion rim between magnetite and feldspar, quite as it does in the gabbros, though less abundantly. Quartz practically disappears in the most basic phases, feldspar augen are seldom seen, and the rock is much more distinctly foliated than is the normal variety.

While there are occasional masses of more basic rock within the normal syenite area, the bulk of it is a border development along the contact with the anorthosite, and to a lesser extent when in contact with the calcareous sediments of the Grenville. Where the border rock is the Laurentian granite gneiss, the syenite becomes more acid rather than

more basic. In this respect it contrasts sharply with the neighboring anorthosite, this latter rock showing everywhere a broad, more basic border, with a slow gradation from anorthosite into anorthosite-gabbro, which in its turn passes into a heavy, basic gabbro at the extreme border, apparently a normal and uniform differentiation border, largely independent of the character of the adjoining rock.

The granitic Syenite

Since the normal syenite is a fairly acid rock, its acid phases do not depart as widely from the type as do the more basic ones. It becomes more acid by increase in quartz and by the plagioclase becoming more albitic. At the same time hornblende tends to replace pyroxene, the feldspar becomes red instead of green, and the quartz tends to take on the lens or spindle form. All intermediate gradations are found between the normal green syenite and the red hornblende granite, both in composition and in color. The granite is normally of coarser grain than the syenite.

This acid variety is also a border phase of the syenite and occurs at the south and west sides of the bathylith, where the adjoining rocks are granitic gneisses involved with amphibolites, of supposed Laurentian age. The apparent great breadth of this acid border as seen on the map is more apparent that real. There is a great amount of a later granite which cuts the syenite here which can be separately mapped only in part, and there is also a considerable amount of a red syenite which differs somewhat from the other and may be a separate intrusion. This also could not be separately mapped. Could these two be excluded, the area of the certain acid syenite would be greatly diminished.

Border Relations between the Syenite and the Granite-gneiss

These are by no means as clear as could be wished. Both sets of rocks are cut by dikes and larger masses of a later granite which is exceedingly like some phases of the granite-gneiss and also not unlike the granitic syenite. The discrimination of the three rocks is difficult at best and frequently is an impossible matter. No certain inclusions of the granite-gneiss have been found in the syenite, and none of the granite dikes found cutting the granite-gneiss have been definitely shown to be dikes of the granitic syenite. They may all be dikes of the later granite. There are some larger masses of the syenite which cut the granite-gneiss, and they are all of rather acid type and become more acid at their borders; yet they are of the green syenite type rather than the red

granitic syenite type. This may well be because the one type is easy of recognition and the other not easy to distinguish from the other granite types, except where it can plainly be traced into the syenite by imperceptible gradations. The areal mapping, however, brings out clearly the asymmetric differentiation of the syenite and the limitation of the granitic syenite to the granite-gneiss border. The granite-gneiss is confidently believed to be the older rock, from evidence seen elsewhere in the region and because this older granite-gneiss is characterized by its associated amphibolite inclusions, which are also abundant here. So the utmost confidence is felt in the associations here urged, even though it is appreciated that they fall short of demonstration.

Border Relations between the Syenite and Anorthosite

Inspection of the geologic map shows that in two localities along the border between these two rocks the syenite has so cut its way into the anorthosite as to cause the disappearance of the entire gabbro border of the latter. The most notable instance is that of the great tongue of syenite which extends eastward from Follensby pond to the Raquette river. North and south of this tongue the gabbro border has a breadth of a mile or more, while east of the tongue there is little sign of it. The tongue is full of inclusions of gabbro and anorthosite gabbro, many of large size, and in the near vicinity of these the syenite becomes much more basic, in precisely the same fashion as it does along the entire border, and in considering the origin of the basic phase these basic fringes around the inclusions are held to have much significance. The syenite here has either cut away or wedged apart the gabbro, and again the inclusions are thought to be helpful in determining which of the two has been done.

The second area of the sort is along the northern border of the map. Here the evidence is not so conclusive as to the cutting away of the gabbro border, since the main contact line is obscured by drift; but no gabbro appears anywhere, the exposures nearest the syenite all being of anorthosite gabbro, and this is all shot full of dikes from the syenite, sometimes of large size and of the basic variety of the syenite, while the exposed border of the main syenite mass tends also to the basic type, as it does in fact everywhere along this border. The drift-covered area which conceals the main contact line is most unfortunate, but the rock of the larger dikes is so identical in all respects with that of the adjoining syenite mass, and with that of the great tongue of syenite which cuts into the anorthosite on the north edge of the map, that the age relations

seem well demonstrated, especially when it is considered that we are dealing with the contact between two bathyliths of contrasted eruptive rocks, and that one of them, near the contact, is full of dikes of a rock similar to the other and with dikes of no other kind, while the reverse is not the case, but instead occasional inclusions of anorthosite are found in the syenite.

Soaked Anorthosite

In the area along the north border of the map, and also farther north on the next map sheet (Saint Regis quadrangle), are a few exposures of a type of a rock which seems most expressively described as anorthosite soaked by syenite. This is the area just noted as lacking the ordinary, non-porphyritic gabbro border, the rock adjacent to the syenite being anorthosite gabbro, in which labradorite augen always occur, often plentifully. In the soaked rock these augen are present, and in so far the rock is distinctly anorthosite; but the matrix is distinctly of the syenite type, having the characteristic green color of that rock and with microperthite as the prevailing feldspar; yet the proportion of plagioclase is larger than in the usual syenite. Chemically also the rock is of an intermediate type. It is an impossible matter to tell how much of the granular portion of the rock is of syenite derivation and how much came from the anorthosite, since in both rocks much of the granulated feldspar is unmarked, showing neither twinning nor intergrowths.

The ferro-magnesian minerals also are very like in both rocks. It is probably for this reason that the existence of soaked rocks along the contact of the syenite and the gabbro border has not been demonstrated. Both are fine grained and lack augen and resemble one another so much that soaked rocks would defy recognition.

It is, however, suggestive that, whereas usually there is little difficulty in discriminating between the gabbro and the basic syenite in the field, in frequent cases rocks are found which defy classification and which may well be soaked rocks. The matter is much simplified so soon as labradorite augen are present, and in the rock under consideration there seems no question but that the augen are of anorthosite derivation, and that a respectable amount of the granular portion is syenite.

The only outcrop of soaked rock seen from which material fresh enough to repay careful study could be obtained is in a rock cut by the railway nearly 5 miles north of Tupper Lake Junction, and hence beyond the map limits. The rock has numerous dark blue feldspar augen, easily proved to be labradorite by the specific gravity and by the extinction angles shown on cleavage pieces. The remainder of the rock

resembles syenite more than anorthosite, and in thin-section the half of the feldspar that shows structures is about equally divided between microperthite and plagioclase (oligoclase to andesine). Chemically also the rock is an intermediate one, as will shortly be shown. The rock is regarded as an anorthosite gabbro which has been penetrated and broken up by syenite which has forced its way between all the granules of the original rock, in precisely the same way that the Laurentian granite-gneisses of the region have invaded and soaked the older amphibolites, separating every grain from its neighbor and inclosing it with a film of granite. Such granite-soaked amphibolites pass over by imperceptible stages into gray gneisses, intermediate rocks which seem to have resulted from the complete assimilation of the one rock by the other. In like manner this soaked anorthosite gabbro is regarded as representing the preliminary stage in the process which, when carried to completion, has produced the basic border of the syenite by its complete digestion of material from the gabbro.

The Anorthosite Outlier in Litchfield Park

Inspection of the map will show this outlier a half mile northeast of Jenkins pond, near the western edge of the map. It is entirely inclosed by syenite. The ordinary syenite of the vicinity is of the granitic type, but as the anorthosite is approached this grades into the basic type, which forms a zone around the anorthosite and sends dikes into it, the numerous exposures on the hill summit showing the relations clearly. We have here, then, a large inclosure of anorthosite in granitic syenite, which latter rock passes into basic syenite as the anorthosite is neared. It is not the most basic type of the rock, but distinctly more so than the normal.

Relations of the Syenite to the Grenville

There is no doubt that the syenite is a much younger rock than the Grenville sediments, but there is much doubt as to the structural relations which obtain between it and the Grenville belt which runs south from Follensby pond and which cleaves the syenite instead of bordering it. No inclusions of undoubted Grenville rocks have been seen in the syenite, nor does the syenite vary in character as the Grenville is neared, except that the acid syenite changes back to the normal variety. Within the Grenville area are occasional small knobs of syenite, which likely represent little offshoots from the main mass which cut the sediments, though lack of contacts prevents any certainty in the matter. There is much in

the field relations to suggest that the Grenville here lies in a downfaulted trough in the syenite, is underlaid by syenite in depth, with the small syenite knobs representing dikes running upward from this underlying mass, and that the contacts with the syenite are therefore fault contacts. If this be true, they have no significance bearing on the general purpose of this paper.

Summary of Field Relations

The Tupper syenite bathylith is in contact with a gabbro on two sides and with granite-gneiss on the other two. The gabbro is a basic differentiation border of anorthosite. The gabbro is a much more basic, the granite a somewhat more acid rock than the syenite. The syenite grades into a much more basic phase as the anorthosite is neared, but becomes somewhat more acid near the granite. Its contacts with both rocks are those of a later intrusive.

Along its contact with the gabbro it seems locally to have cut away the entire gabbro border from the anorthosite. It holds frequent large inclusions of anorthosite gabbro, around which it becomes more basic. Anorthosite gabbro soaked by syenite is found. Rocks are also found which are so distinctly intermediate between the gabbro and the basic syenite that they defy classification as either the one or the other. Around a large inclusion of anorthosite gabbro in the granitic syenite a fringe of basic syenite has developed.

These relations are readily explained on the assumption that there has been actual incorporation and digestion of material from the surrounding rocks by the syenite, and that the digestion has mainly been a border phenomenon. Nothing that was observed is antagonistic to such an explanation. No other solution that will at all account for the observed relations suggests itself. It is therefore an instance which needs to be taken into account when the general question of the possibility of such assimilation taking place is under consideration.

Chemical Evidence

It has been frequently and cogently urged that, in case one rock had been assimilated by another, the resultant rock should have a distinctly intermediate composition. It is no part of the purpose of this paper to consider the validity of this point. For purposes of argument it is granted, and it remains to be seen whether it has any antagonistic bearing in this specific instance.

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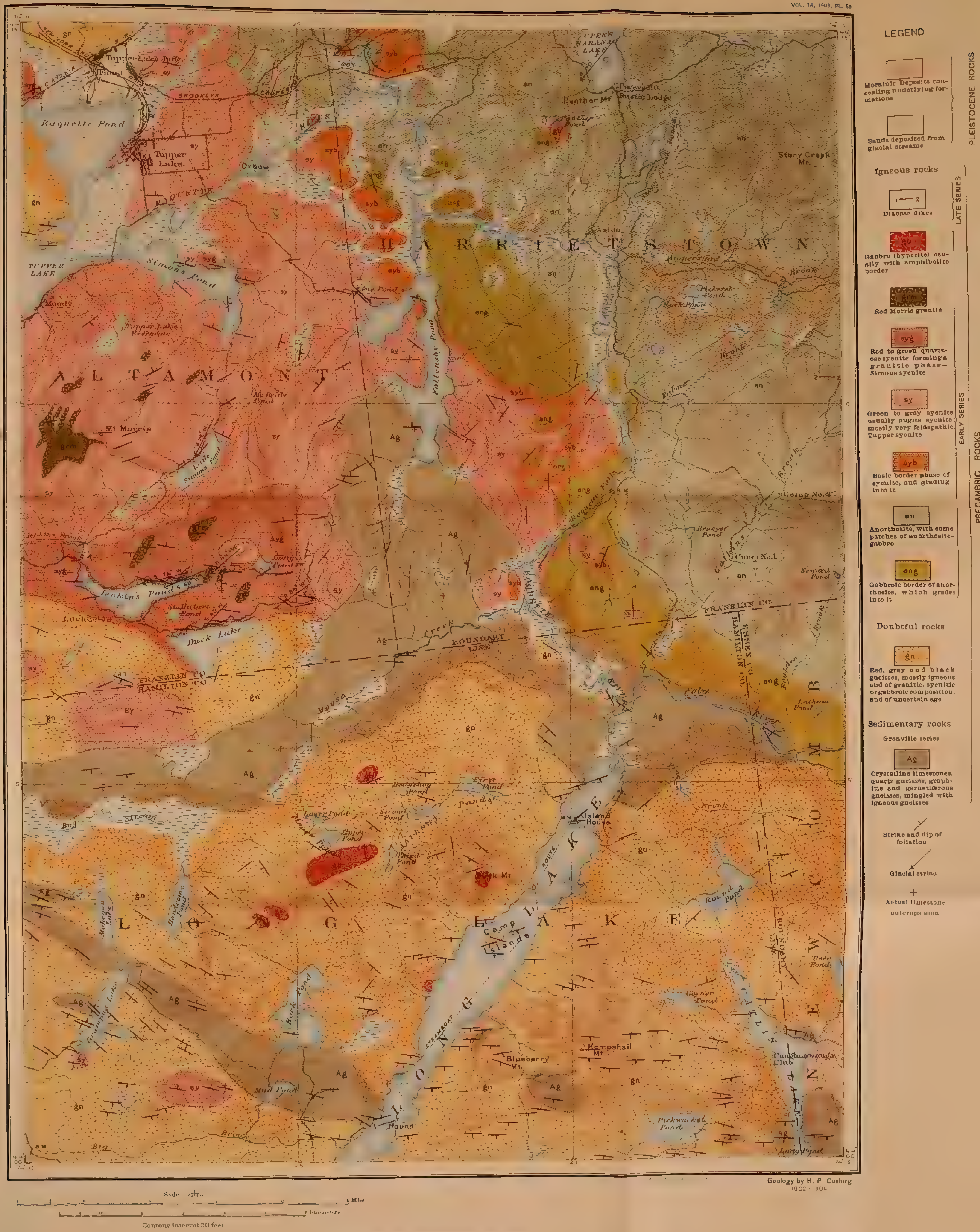

GEOLOGY OF LONG LAKE QUADRANGLE, NEW YORK

Reproduced by the courtesy of the New York State Museum

The rocks concerned are all igneous and the syenite and anorthosite seem surely derivatives from the same parent magma and of no great difference in age; hence they present no striking differences in composition. The granite-gneisses are in all probability of much greater age and from a different magma, but are nevertheless related igneous rocks and have a composition quite like that of the granites which did arise from the anorthosite-syenite magma. Because of this close chemical relationship the chemical evidence is likely to be much less positive in character than would be the case were the rocks possessed of more prominent differences in composition.

It is also the case that the rock of the syenite and anorthosite bathyliths is so variable that it is an impossible matter at the present time to arrive at any exact notion regarding their average composition.

Furthermore, if the syenite has digested material from the anorthosite the field relations make it clear that the rock mostly concerned is the gabbro border along with a wholly uncertain amount of anorthosite gabbro, and the precise proportions and composition of this mixture is again an uncertain matter.

Chemical Analyses and Discussion

	1	2	3	4	5	6	7	8
SiO_2	44.77	47.42	51.62	54.47	54.62	54.38	54.10	57.00
Al_2O_3	12.46	17.34	24.45	26.45	26.5	20.53	17.45	16.01
Fe_2O_3	4.63	4.91	1.65	1.3	.75	2.78	4.52	10.3
FeO	12.99	10.22	5.3	.66	.56	5.5	6.47	
MgO	5.34	5.21	1.21	.69	.74	1.99	2.33	1 62
CaO	10.2	8.09	9.97	10.8	9.88	5.39	6.17	6.20
Na_2O	2.47	3.48	3.49	4.37	4.5	5.2	3.81	4.35
K_2O	.95	1.89	1.27	.92	1.23	3.4	3.06	3.53
H_2O	.6	1.13	.72	.53	.91	.5	.57	.15
CO_2	.37	......	......	......	......	......	......	......
TiO_2	5.26	3.6	......	......	......	.09	.19	......
P_2O_5	.28	.06	.01	......	......	.15	.88	......
Cl	......	.21	......	......	......	.03	......	......
F	......	......	......	......	......	.03	.05	......
S	.26	......	......	......	......	......	.14	......
MnO	.17	.06	.1	......	......	.01	.35	......
BaO	Trace	.04	......	......	......	.16	.10	......
Total	100.75	100.01	99.79	100.19	99.7	100.03	100.19	99.16

	9	10	11	12	13	14	15	16
SiO_2	59.7	61.01	63.45	65.65	66.72	68.5	68.18	69 24
Al_2O_3	19.52	15.36	18.38	16.84	16.15	14 69	16.15	14.85
Fe_2O_3	1.89	2.98	1.09	4.01	1.23	1.34	1.26	2.62
FeO	4.92	7.77	2.89		2.19	3.25	1.00	
MgO	.78	.78	.35	.13	.73	.26	.64	.97
CaO	3.36	4.05	3.06	2.47	2.3	2.2	2 48	2.1
Na_2O	5.31	3.68	5.06	5.27	4.36	3.5	4.22	4.3
Ka_2O	4.14	3.9	5 15	5.04	5.66	5.9	5.59	4.33
H_2O	.52	.49	.3	.3	.77	.4	......	.07
TiO_2	......	......	.07	......	......	......	......	......
P_5O_5	......	......	......	......	......	.03	0 1	......
Cl	......	......	......	......	......	......	0.02	......
F	......	......	......	......	......	......	......	......
S	......	......	......	......	......	......	0.03	......
MnO	.09	.08	Trace	......	.07	.1	......	.45
BaO	......	......	.13	......	......	.05	......	......
Total	100.23	100.1	99.73	99.71	100.18	100.22	100 02	99.56

1. Norite, wall rock of titaniferous magnetite deposit, Lincoln pond, Elizabethtown, Essex county, New York. Description by J. F. Kemp, analysis by W. F. Hillebrand, U. S. Geological Survey. 19th Ann. Rept., 1899, part 3, p. 407.

2. Gabbro (hyperite), dike near Nicholville, Hopkinton, Saint Lawrence county, New York. Brief mention by H. P. Cushing. 16th Ann. Rept. New York State Geologist, 1896, p. 22. E. W. Morley, analyst.

3. Anorthosite gabbro, Carnes's quarry, Altona, Clinton county, New York. Description by H. P. Cushing, analysis by E. W. Morley. 19th Ann. Rept. New York State Geologist, p. r58.

4. Anorthosite, summit of Mount Marcy, Keene, Essex county, New York. A. R. Leeds, analyst. 30th Ann. Rept. New York State Museum, p. 92.

5. Anorthosite, Keene township, Essex county, New York (precise locality not given). A. R. Leeds, analyst. 30th Ann. Rept. New York State Museum.

6. Anorthosite showing transition to augite syenite, cut by New York Central and Hudson River railroad nearly 5 miles north of Tupper Lake Junction, Altamont, Franklin county, New York. E. W. Morley, analyst. 20th Ann. Rept. New York State Geologist, p. r68.

7. Basic syenite (andose) from near Raquette Falls, New York. Analysis by E. W. Morley. Bulletin no. 115, New York State Museum, p. 514.

8. Basic syenite from Natural Bridge, Diana, Lewis county, New York. C. H. Smyth, Jr. Bulletin of the Geological Society of America, vol. 6, p. 274.

9. Augite syenite (laurvikose), road from Tupper lake to Wawbeek. Bulletin no. 115, New York State Museum, p. 514.

10. Augite syenite (harzose), by New York Central and Hudson River railroad, 3½ miles north of Tupper Lake Junction. Op. cit., p. 514.

11. Augite syenite (pulaskose), Loon lake, Franklin county, New York. Bulletin of the Geological Society of America, vol. 10, pp. 177-192.

12. Augite syenite, near Harrisville, Diana, Lewis county, New York. C. H. Smyth, Jr. Bulletin of the Geological Society of America, vol. 6, pp. 271-274.

13. Augite syenite (toscanose), Little Falls, Herkimer county, New York. Op. cit., p. 514.

14. Quartz syenite (toscanose), New York and Ottawa railroad, 2½ miles south of Willis pond, Altamont, Franklin county, New York. Op. cit., p. 514.

15. Quartz syenite, near south end of Big Tupper lake. Microscopic analysis.

16. Granitic gneiss, Trembling mountain, Quebec. F. D. Adams. American Journal of Science, July, 1895, p. 67. W. C. Adams, analyst.

Analyses 9, 10, 11, 13 and 14 by E. W. Morley.

It is to be noted that these analyses are from widely scattered localities, though all of rocks believed to be the equivalents of those under discussion. Only numbers 7, 9, 10, and 15 are from the immediate district. It is thought that the syenite analyses give a good representation of the variation in composition of the Tupper bathylith; but it is feared that the anorthosite gabbro and gabbro analyses may not serve as well as representatives of the similar rocks under consideration here. None of the analyses were made with the purposes of this discussion in mind, and an element of uncertainty necessarily enters into their use.

The basic syenites (analyses 7-10) are thought to be owing to assimilation of gabbro and anorthosite gabbro from the syenite border. From the field situation of the most basic of these (number 7) it is judged that gabbro, rather than anorthosite gabbro, has been the rock digested. Study of the slides of this gabbro leads to the belief that its composition is more nearly represented by the rock of analysis 2 than of analysis 1, though considerable uncertainty prevails as to whether either is a close representative of its composition. Therefore a calculation of the com-

position of a mixture of this rock with a normal syenite (analysis 11) in proper proportion to give a silica percentage equal to that of the basic syenite of analysis 7 is presented for comparison with the rock itself. This mixture would consist of 58.3 per cent gabbro and 41.7 per cent syenite. These relative percentages of the gabbro and syenite form columns 1 and 2, their sums give the composition of the mixture in column 3, and in column 4 is the analysis of the basic syenite for comparison. The two iron oxids are put together and only the principal oxids included in the table.

	1	2	3	4	5
SiO_2	27.65	26.45	54.1	54.1	....
Al_2O_3	10.11	7.66	17.77	17.45	+ .32
Fe_2O_3	8.82	1.66	10.48	10 99	— .51
MgO	3 04	.15	3.19	2.33	+ .86
CaO	4.72	1.27	5.99	6.17	— .18
Na_2O	2.03	2.11	4.14	3.81	+ .33
K_2O	1.1	2.15	3.25	3.06	+ .19
	57.47	41.45	98.92	97.91	....

In view of the many uncertainties connected with the calculations, it has not been deemed necessary to recalculate the footings to 100 per cent. It is thought that they show just as clearly the size and importance of the discrepancies as they stand as if so recalculated. Though there is a considerable difference in the magnesia percentage of the two, it is not thought to be of a higher order than the differences in magnesia content shown by the rocks of both classes of similar silica content when followed from place to place. The other differences are certainly of no higher order. The calculation is therefore thought to indicate that in this instance the chemical evidence is not opposed to the suggested hypothesis. Neither the gabbro nor the syenite used in the calculation are from the immediate region, though it is thought that each could be closely duplicated there. Each rock also varies considerably from place to place, and it is an open question whether the syenite and the gabbro from the Tupper Lake region would or would not have furnished a closer agreement had analyses been available.

This very basic syenite is not the average variety of the basic rock, but the most extreme type met with which furnished material sufficiently fresh for chemical analysis. The only available analysis of syenite of more average basicity is that from the syenite intrusion inlying in the anorthosite nearly midway on the northern border of the map. The

adjacent rock along this portion of the border is anorthosite gabbro. If there has been incorporation of material from the anorthosite by this syenite, it is but fair to assume that the assimilated rock was not mere gabbro, but anorthosite gabbro. No analysis of the typical anorthosite gabbro of the region is available, the rock from Rand hill, Clinton county, a distant locality where the rock occurs as an outlier instead of as a portion of the great anorthosite bathylith, being the only one so far analyzed. Like the rock of most of the outliers, this is of a somewhat abnormal type, being certainly higher in alumina and lime and lower in iron and magnesia than the usual anorthosite gabbro. Study of the slides of the Tupper Lake rock, however, suggests that its composition would be quite similar to a half and half combination of this Rand Hill rock, whose analysis appears as number 3 of the table, with that of the gabbro of number 2, and the calculation is then made of a combination of this with the normal syenite of number 11 in the proper proportions to obtain a rock of the silica percentage of the medium basic syenite of number 9. In the following table columns 1 and 2 are the respective analyses of the gabbro and anorthosite gabbro, column 3 a combination of 50 per cent of each, column 4 the syenite, column 5 the result of combining 3 and 4 on the basis of 26.8 per cent of the former and 73.2 per cent of the latter, while column 6 gives the analysis of the basic syenite for comparison with the calculated composition of the mixture, and column 7 the discrepancies between the two.

	1	2	3	4	5	6	7
SiO_2	47.42	51.62	49.52	63.45	59.7	59.7	....
Al_2O_3	17.34	24.45	20.89	18.38	19.05	19.52	— .47
Fe_2O_3	15.13	6.95	11.04	3.98	5.87	6.81	— .96
MgO	5.21	1.21	3.21	.35	1.11	.78	+ .33
CaO	8.09	9.97	9.03	3.06	4.66	3.36	+1.3
Na_2O	3.48	3.49	3.48	5.06	4.63	5.31	— .68
K_2O	1.89	1.27	1.58	5.15	4.19	4.14	+ .05
	98.56	98.96	98.75	99.43	99.21	99.62	....

Here is a large discrepancy in lime and considerable ones in other constituents. These are thought to be due in part at least to unsoundness in the original assumption that the rock of column 3 is closely akin to the anorthosite gabbro of the district, the trouble arising from the abnormal character of the rock of column 2. But inspection of analyses 8-10 of the original table, all of which are basic syenites of not widely differing silica percentages, shows much variation in all the constituents which show the main discrepancies here, so that if either number 8 or

number 10 had been used in the calculation instead of number 9 the discrepancies would have varied largely, or, in other words, that the differences between numbers 5 and 6 of this table are of the same order as those between 8 and 9 or 9 and 10 of the original table. It is not thought, therefore, that the calculation can be regarded as furnishing an argument against the general hypothesis, though it is not maintained that it is of any especial value, owing to the assumptions which enter into it.

In attempting a calculation of the soaked rock (analysis 6 of the original table) the same difficulty is met as in the previous case, namely, lack of an analysis of the anorthosite gabbro near by. From study of the thin-section this is estimated to have a composition similar to that of a mixture of the analyzed gabbro and anorthosite gabbro in the proportion of 35 per cent of the former and 65 per cent of the latter. Labradorite augen are more abundant and conspicuous than in the previous case, where a half and half mixture was assumed. Obviously there is the same uncertainty here as appeared in the previous calculation, the somewhat abnormal character of the anorthosite gabbro of the analysis. Since the calculation is precisely similar to the last, the analyses of the gabbro and anorthosite gabbro are not repeated and column 1 of the following table is the combination of 35 per cent and 65 per cent of the two respectively. The adjacent syenite which is supposed to have soaked the other rock is of about the basicity and character of that of analysis 9 of the original table, appearing here in column 2. These two are combined in the proportion of 56 per cent of the former and 44 per cent of the latter, the result appearing in column 3, with the analysis of the soaked rock in column 4 and the discrepancies in column 5.

	1	2	3	4	5
SiO_2	50.15	59.7	54.36	54.38	....
Al_2O_3	21 96	19.52	20.87	20.53	+ .34
Fe_2O_3	9.82	6.81	8.5	8.28	+ .22
MgO	2.61	.78	1.8	1.99	— .19
CaO	9.31	3.36	6.69	5.39	+1.3
Na_2O	3.49	5.31	4.3	5.2	— .9
K_2O	1.49	4.14	2.65	3.4	— .75
	98.83	99.62	99.17	99.17	....

There is more lime and less alkalies in the calculated mixture than in the actual rock, just as was true in the previous calculation. This might suggest either an error common to both, due to the assumed mixture of

gabbro and anorthosite gabbro not adequately representing the character of the anorthosite gabbro here, or else might be regarded as a difference which threw doubt on the suggested origin of the two rocks concerned. To the writer the former seems vastly the more probable, since the anorthosite gabbro used is known to be a somewhat abnormal rock, and the similarities between the calculation and the analysis seem to him also much more significant than the differences. It is not being argued that they afford evidence of the truth of the advanced hypothesis, but only that they do not furnish ground for an argument against it.

So far as the writer is aware, no analyses of the granitic gneisses of the Adirondacks have been made, so that recourse must be had to Canadian analyses in order to get any data for comparison with the acid syenites. The only one of these known to the writer is that quoted as number 16 of the table of analyses and repeated as column 1 of the following table. With it are two analyses of granitic phases of the syenite, numbers 14 and 15 of the original table.

	1	2	3
SiO_2	69 24	68.5	68.18
Al_2O_3	14.85	14.69	16.15
Fe_2O_3	2.62	4.59	2.26
MgO	.97	.26	.64
CaO	2.1	2.2	2.48
Na_2O	4 3	3.5	4.22
K_2O	4.33	5.9	5.59

These are such trifling differences in composition that there is little to be gained by making calculations. The two syenites differ from one another as much as either differs from the granite. It is, however, to be noted that the syenites are nearly as siliceous as the granite-gneiss, so that if they have been produced from the normal syenite of about 63 per cent of silica by digestion of granite no more acid than this, the amount of granite digested must enormously exceed the syenite in the mixture, which seems most improbable. Experience with other syenite bathyliths of the region has led the writer to the view that they have a normal tendency to produce a more acid differentiation border. But the detailed field work necessary to establish that view is as yet undone. If it be true, it follows that the acidity of these syenites is due in whole or part to this normal differentiation, and only in part or not at all to incorporation of material from the granite-gneiss. Such incorporation would, however, evidently yield a rock quite like the acid syenite, so that

there is no chemical difficulty in the way. If the syenites of the region do tend to differentiate a more acid border, the basic border adjacent to the anorthosite is all the more remarkable, and it is there that the major part of the field evidence suggesting incorporation is found. The instance of the acid syenite in Litchfield park passing into basic syenite around the large anorthosite inclusion there will be recalled in this connection.

In conclusion it may be said that while the chemical evidence is by no means of satisfactory nature, owing mainly to the lack of selected analyses made with this problem in view, yet that it does not seem to afford any valid argument in opposition to the field evidence, which does distinctly suggest the incorporation and digestion of material from the surrounding rocks, especially from the anorthosite, as the cause of the peculiar differentiation of the syenite.

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ORIGIN OF METEOR CRATER (COON BUTTE), ARIZONA*

BY HERMAN L. FAIRCHILD

(Read before the Society, December 29, 1906)

CONTENTS

INTRODUCTION

The remarkable crateriform pit in central Arizona, famous on account of its association with the Canyon Diablo siderites and through the writings of Dr G. K. Gilbert, has lately come into special geologic interest through the explorations of the Standard Iron company. Appreciating the money value of the rare elements associated with a large quantity of meteoric iron and believing that an enormous mass was imbedded in the crater, four men with commendable enterprise and scientific interest, backed by financial ability, acquired the crater and adjacent land under mining law, and for four years have been probing the crater and its rim. Recently two of the company, Mr D. M. Barringer and B. C. Tilghman, have published articles giving the results, to that date, of their explorations.†

* Manuscript received by Secretary of the Society from Censor October 31, 1907.

† D. M. Barringer: Coon mountain and its crater. Proc. Acad. Nat. Sci., Philadelphia, December, 1905, pp. 861-886.

B. C. Tilghman: Coon Butte, Arizona. Ibid., pp. 887-914.

The writings of Doctor Gilbert are in the 13th Ann. Rept. U. S. Geological Survey, part 1, p. 98; 14th Ann. Rept., p. 187; Science (new series), vol. 3, 1896, pp. 1-13, with illustrations; Geological Society of Washington, presidential address, March, 1896.

The original descriptions of the Canyon Diablo siderites, with notice of the crater, was published by A. E. Foote in Proc. Am. Assoc. Adv. Sci., vol. 40, 1892, pp. 279-283; also in Amer. Jour. of Sci., vol. 42, 1891, p. 413.

A detailed analysis of the siderite was published by O. A. Derby, in Amer. Jour. of

Up to the present time more than 50 pits and trenches have been excavated in the debris of the outer slopes; seven shafts have been dug in the floor of the crater, three of them to the depth of 200 feet or over; and eight drill holes have been sunk in the central part of the crater, four of which passed entirely through the white sandstone and penetrated the underlying dark red sandstone at a depth of 880 feet below the crater floor, to a total depth of over 1,050 feet.

These explorations have developed a mass of new and important facts which favor the theory of meteoric impact origin, and certainly rule out the hypothesis of igneous or volcanic origin. The writer visited the crater during the past summer and studied the phenomena under the guidance of Mr S. J. Holsinger, one of the mining company, who has been camping on the crater rim for four years and directing the exploration.

Professor Branner had visited the crater a few weeks earlier, and the writer agrees with him that if the phenomena are not of meteoric origin then they constitute the most interesting geological puzzle of the present time.

To Messrs Barringer, Tilghman, and Holsinger the writer is under obligation for courteous assistance. Their two papers, noted above, contain an array of interesting facts relating to the crater phenomena. The purpose of this writing is to bring before the Geological Society the more salient and important facts.

The Rock Strata

The rocks belong in the Grand Canyon series. The outcrops in the crater and the deep drilling give the following section:

1. Red sandstone, thickness 30 to 40 feet.
2. Aubrey limestone, yellowish, 250 ± feet.

Sci., vol. 49, February, 1905, pp. 101-110. Other writers on the irons are Brezina, Cohen, and Huntington.

The stony meteorite referred to by Mr Barringer (p. 883 of his paper) was described by J. W. Mallet, in Amer. Jour. of Sci., vol. 21, May, 1906, pp. 347-355.

Dr J. C. Branner presented the papers of Messrs Barringer and Tilghman before Section E, American Association for the Advancement of Science, at the Ithaca meeting, June 29, 1906, with the results of his own study of the phenomena, which favored the view of meteoric origin of the crater. This is reported in Science, vol. 24, September 21, 1906, pp. 370-371.

At the 10th Session of the International Geological Congress, in Mexico, September 14, 1906, H. L. Fairchild presented the new facts favoring the impact origin of the crater, and exhibited the various materials. The record will be found in Compte Rendu, X Session, Congres Geol. Inter., Mexico, 1906.

O. C. Farrington has analyzed the siderite oxides ("iron shales"), and discussed their origin and relation to the typical Canyon Diablo irons, in Amer. Jour. of Sci., vol. 22, October, 1906, pp. 303-309.

FIGURE 1.—DISTANT VIEW OF THE CRATER RIM, LOOKING EAST

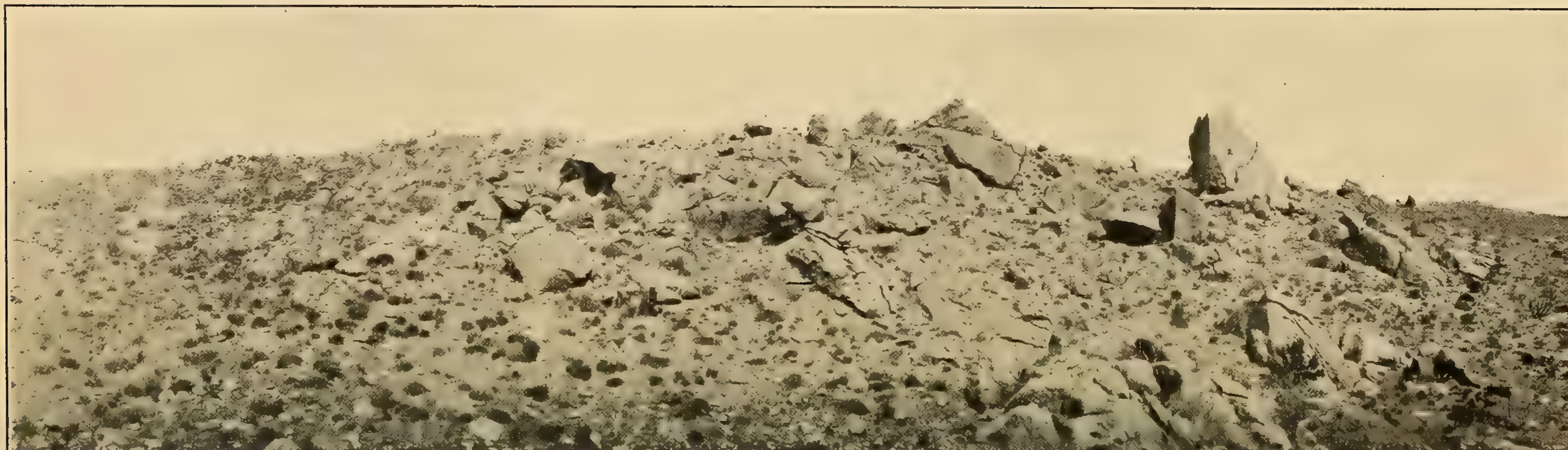

FIGURE 2.—WRECKAGE FROM THE CRATER. WEST SIDE OF RIM. THE LARGE BLOCK IS LIMESTONE, 30 X 25 FEET

METEOR CRATER, ARIZONA

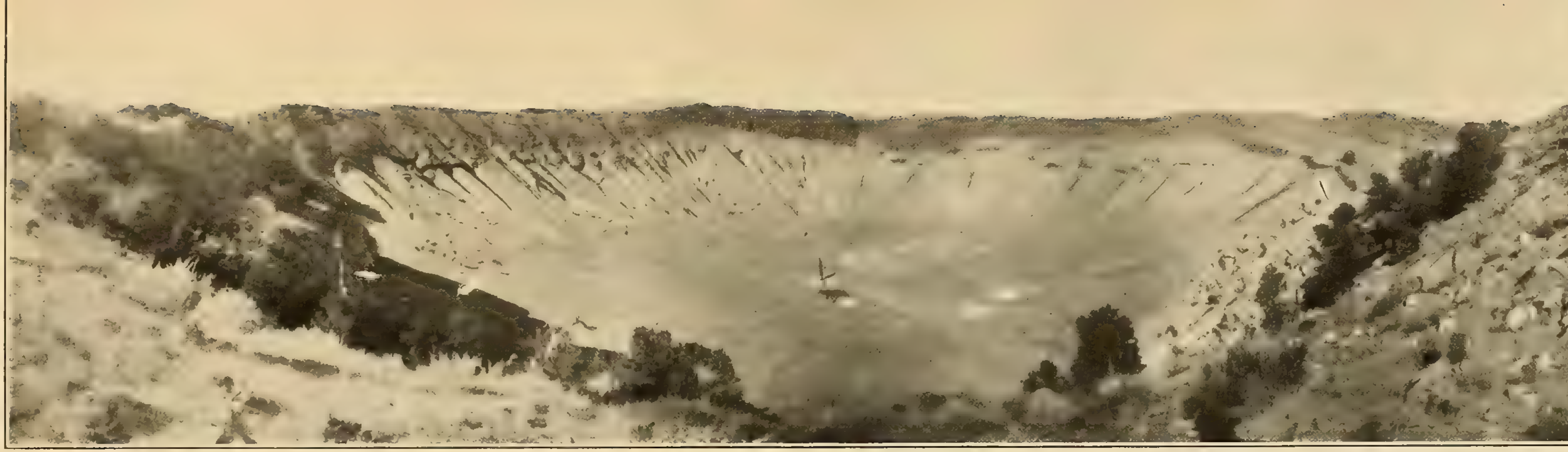

Figure 1.—General View of Crater, looking North

Figure 2.—View looking Southeast

METEOR CRATER, ARIZONA

3. White sandstone with some yellow and pink, about 1,000 feet.

4. Dark red sandstone, thickness unknown.

The uncertainty as to the precise thickness of the limestone is due to the broken and disturbed structure of the uptilted beds in the crater walls. Mr Barringer gives the thickness as 200 to 350 feet. No drilling has been done on the plain outside the crater, where the rocks are undisturbed.

The Crater

Many interesting and important details relating to the crater and the debris will be found in the papers by Messrs Barringer and Tilghman and in the earlier writings by Doctor Gilbert, but only the more important facts will be given here.

The pit or "crater" is circular and bowl-shaped, 4,000 feet in diameter at the top, and toward 600 feet deep, measuring from the rim. The upper part of the walls are steep cliffs (see plate 55) of limestone and sandstone, uptilted so as to have a quaquaversal dip of 30 to 40 degrees, and in places is greatly shattered and crushed. The lower part of the walls is a talus slope produced by many centuries of stormwash on the broken cliffs. Just previous to the writer's visit to the crater (September, 1906) a heavy storm or "cloudburst," characteristic of the arid region, burst exactly over the crater and illustrated the talus-making process. The northern trail leading down the crater wall was obliterated and

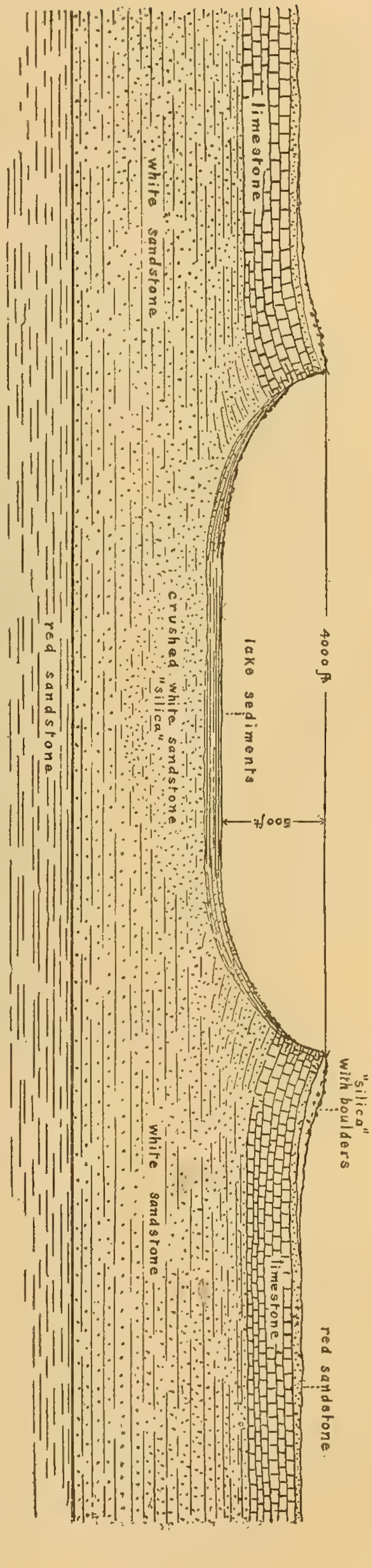

FIGURE 1.—*Vertical Section through Meteor Crater, Arizona.*

Horizontal and vertical scales are equal.

trains of boulders were swept far out on the floor of the crater, while the shaft-house, tool-house, and other buildings in the middle of the pit had their floors buried in mud.

It would appear that the original diameter of the crater must have been appreciably less than now, the walls steeper, and depth of the pit greater. The nearly circular floor of the crater is about 1,800 feet across, with a nearly flat, or gently rolling, surface. The floor consists of aqueous sediments, with intercalating inwashed beds of the talus about the margin. These sediments have been found to average depth of 70 feet, and contain vegetal or peaty layers, beds of diatomaceous material, pond snails, and a stratum of volcanic dust and lapilli from one-fourth of an inch to three inches in thickness; also scattered boulders, which were probably rolled in on the lake ice or rafted in on floating ice cakes. The volcanic debris suggests that the crater antedates the latest volcanic eruptions of the region. At present no water stands in the crater, but it is encountered 200 feet beneath the floor, or over 600 feet below the surface of the plain, which suggests possible climatic change. Mr Holsinger states that cedars growing on the crater rim are over 700 years old.

The bottom of the pit when formed must have been at least 540 feet below the level of the plain and about 750 feet below the rim, the latter now being, after centuries of storm-wash, 130 to 160 feet high above the surrounding plain. This crater rim consists of the uplifted rocks capped by an enormous mass of rocks debris, giving the appearance from a distance of a range of low hills with rough surface (see plate 54).

Volcanic Theory untenable

Beneath the central area of the crater the red standstone (number 4) is found in place beneath the white sandstone (number 3), which shows the absence of any chimney or volcanic pipe of considerable size and positively rules out any explosion from beneath. The conception of a vapor explosion in the thick white sandstone is ruled out by the existing phenomena. Mr Barringer and Mr Tilghman have given the facts bearing on this theory, and in unpublished writing Mr Tilghman has clearly discussed the mechanics and the subsequent effects of a steam explosion. The white sandstone, nearly 1,000 feet thick and underlying all the country, is very porous and would contain a large volume of water. The pressure of any heated water or vapor sufficient to throw the mass of rock out of the pit must have existed through an immense horizontal extent of the strata, and a long time would have been required for entire relief of the pressure through the vent, and with decided hot spring or

fumarolic or solfataric phenomena. With all the careful study, there has not been found the least evidence of any volcanic or igneous activity of any kind. The nearest volcanic phenomena are at the San Francisco mountains, about 15 miles distant. Further, the pulverized character of the rock debris, described below, is not consistent with the idea of an explosion nor with the digestive action of heated waters. The explosive or volcanic theory has not a single fact to stand on. On the other hand, the investigation has developed several remarkable facts which are well explained by the impact theory of the crater genesis.

The powdered Sandstone, "Silica"

It has been found that the greater part of the enormous mass of rock debris or ejectamenta on the outer slopes of the crater rim is a very fine, white, quartz powder; and the same material occupies the pit, beneath the inwashed beds, to the depth of several hundred feet. This "silica" (using the term common on the ground) is certainly only the crushed white sandstone. Much of it is as fine as flour, 50 per cent of it passing through a number 100 sieve, but under the microscope it shows its character as crushed crystalline quartz. Quoting from Mr Tilghman (page 896):

> . . . "it is mostly as white as snow and consists of over 99 per cent silica, although here and there small areas or deposits will be of a slightly yellowish color from the yellow limestone and contain a little carbonate of lime (although this has to a great extent been leached out of it), and much more rarely of a reddish color, either stained by or produced from the top stratum of red sandstone. Under the microscope it is seen to consist of minute fragments of clear transparent quartz with edges and points of extreme sharpness, and no signs of any rounding are anywhere visible upon its particles. In some areas the material is composed of this material exclusively. . . . But in other localities it can be found containing a greater or less percentage of broken sand grains among it which have escaped being crushed out of all recognizable shape. A continuous series of material can be found containing more and more broken sand grains . . . on up to the solid sandstone rock. Its general microscopic appearance is identical with that of a handful of glass fragments produced by a blow. It cannot be quite imitated by grinding the sand grains in a mortar, as the edges and points of the powder thus produced are more blunted and rounder and broken than those of the silica. But it is very closely duplicated by the finest powder produced by firing a high-power rifle bullet against a block of the sandstone."

On the surface of the wreckage slopes the silica has been so removed by stormwash and winds that large fragments of the several rocks occupy most of the present surfaces, in size up to thousands of tons (see plate

54); but the silica is everywhere encountered in the pits and trenches. Fragments of the rocks of all sizes are scattered irregularly through the silica, but quite clean sections of the powder are found up to 40 feet deep; and it is the predominating material in contact with the upturned red sandstone. On the south side of the crater rim the silica is exposed in a ravine some 600 feet long and 8 to 10 feet deep. Imbedded in the silica are not only quantities of the limestone and the red sandstone, but also masses of the white sandstone in all stages of the crushing. Some of the blocks preserve the bedding planes and oblique lamination and to the eye appear as firm, unaltered rock, but under a little pressure crumble in the hand into the flour-like silica. By the explorers these have been aptly called the "ghost" sandstone.

Two metamorphic forms of the sandstone are found which are of special significance. One form ("variety A") has a higher density with a slaty structure, the cleavage having no relation to the rock lamination. This form seems to be a direct product of intense compression. It is found in the drill holes to the depth of over 400 feet.

The other peculiar form ("variety B") of the transformed sandstone is a very light, cellular or pumiceous structure, of considerable firmness and rigidity, but so light that it will float on water like a piece of wood. This pumiceous form is rare, but is reported from the drillings to the depth of 160 feet below the sediments. Under the microscope it is found to be mainly composed of amorphous silica, but with scattered particles of crystalline quartz. It would seem to be the natural product of the intense heat of compression on portions of the sandstone which contained sufficient water, perhaps along the joints of the strata, to effect an aqueo-igneous fusion.

These three forms of the crushed sandstone, the powdery, slaty, and cellular, are the products which should be expected from a tremendous crushing blow with resulting heat. They are not the products of an explosion, which would shatter the rocks, but would not reduce them to dust. The first two forms are also entirely opposed to the hypothesis of aqueo-igneous origin of the crater, and the cellular form is probably unknown in hot springs and fumarolic deposits.*

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* The mechanics of impact by projectiles, as relating to the origin of the sandstone powder, is well stated by Mr. Tilghman as follows (pages 899-890):

"To account for the presence of this silica powder on the theory that the hole was formed by a great projectile requires a short preliminary study as to the yielding of hard, brittle, and practically incompressible material before a projectile or other blow, or even quiet pressure, for the method is much the same in both cases. Briefly, the way in which substances yield to either pressure or blow in excess of their power of resistance is that a cone of material, with an apex angle of about 90 degrees, is compressed downward into the solid mass of the material from the point of impact. This cone parts from the overlying material, crushes into powder under the force of the pressure or

To summarize: all the phenomena thus far found in the long and careful exploration of the crater, the distribution of the wreckage both inside and outside, and the composition and structure of the materials seem to be fully and satisfactorily explained on the theory of impact by a celestial bolide of high velocity, and do not fit any other theory.

The Nickel-iron Oxides

The association of the Canyon Diablo siderites with the crater needs no discussion here, but it may be said that the distribution of the irons over the crater rim and the surrounding plain has been found much more general and extended than was formerly known; but an important new fact is the general occurrence along with the irons, and also in the wreckage, of iron oxides of meteoric origin. The existence of these oxide masses is not a new discovery, having been noted by Doctor Foote, but their meteoric nature, their abundance and wide dissemination, and their intimate relationship to the phenomena have not been appreciated. Possibly the oxide fragments were confused with the abundant nodules of ordinary limonite derived from the country rocks and scattered over the plain and crater rim.

Many oxide masses, up to large size, have a globular form with more or less concentric structure and lamination, apparently due to weathering and hydration from an original metallic mass. A siderite core is frequently found which appears on cut and etched section much like the Canyon Diablo irons, though the crystalline structure seems somewhat different. Such masses with metallic cores have been found in the silica of the outer slopes to the depth of 27 feet, while multitudes of fragments, evidently derived from disrupted nodules, are found over and in

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blow, and this powder, being still further compressed, transmits the pressure upon it in all directions, somewhat like a fluid, although not equally in all directions. The pressure thus generated in the very substance of the material seeks relief and forces a yielding of the solid material around it, which, of course, occurs along the line of least resistance, and bursts the surface upward and outward into a cone-shaped crater around the point of impact or pressure, the angle of which depends largely upon the nature of the material. . . .

"The bearing of this upon the formation of a rim composed in part of fine powder is as follows: The broken rocks and debris that are expelled from the hole get their velocity imparted to them by the push of an inelastic powder, and not by a compressed elastic gas, and thus, when both rock fragments and powder have progressed far enough to free themselves from the pressure of the penetrating projectile, they fly on together, mixed powder and rocks, at the same velocity. This powder is not dust in the ordinary acceptation of the word, as fine powder mixed with a large quantity of air, which takes a long time to settle out, but is almost unmixed with air in solid masses, particle to particle, like flour in a barrel, so to speak; which masses obey the laws of projectiles and falling bodies, irrespective of the exceedingly minute particles of which they are formed, and are thus deposited in the rim in mixture with and under and over the solid rock masses which accompanied it in its flight, and as quickly."

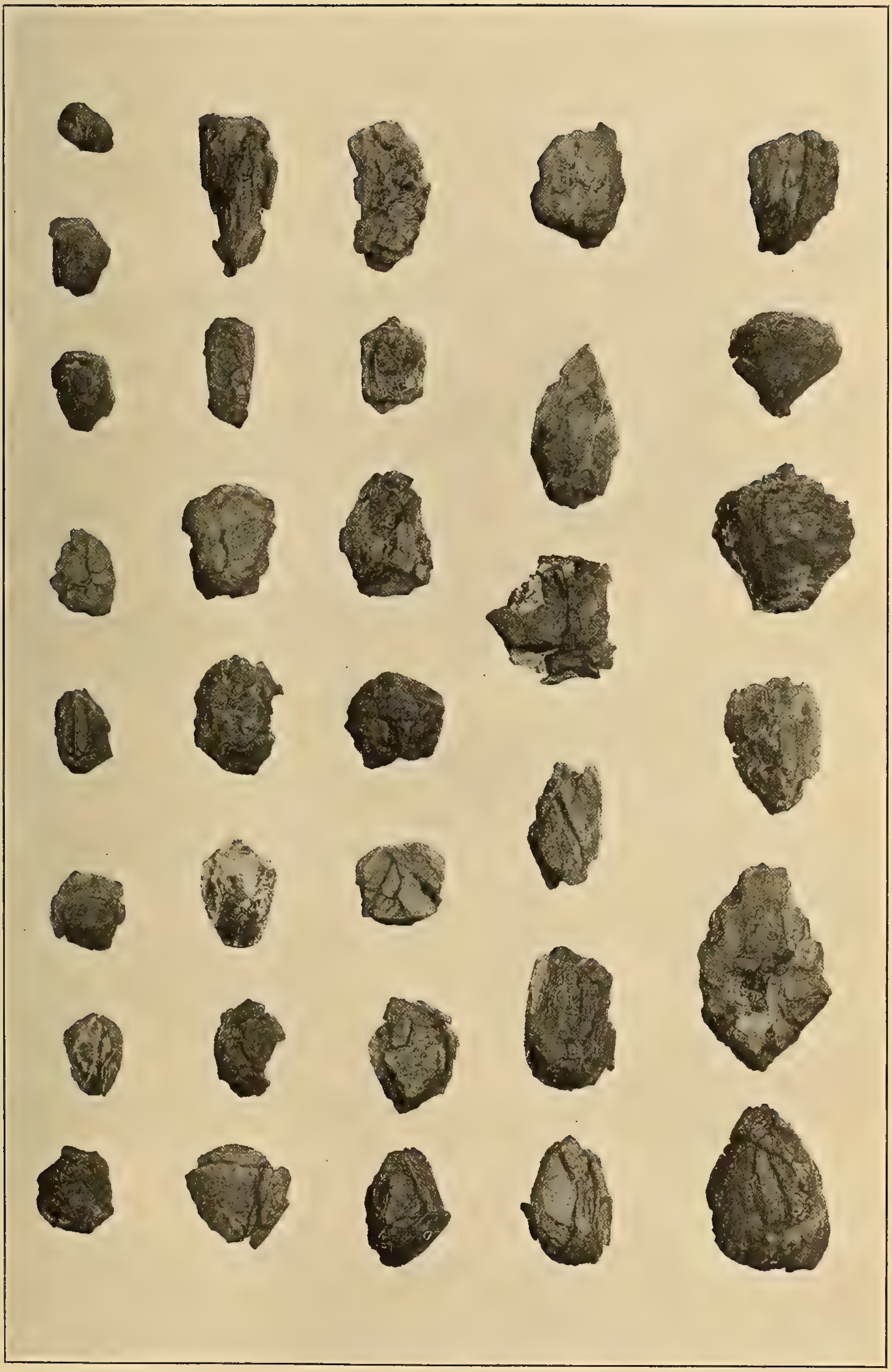
the silica and on the plain. The concentric lamination of the oxides has led the explorers to call the material "iron shale." In the hydration process it is apparent that large quantities of the material have entirely disappeared, but innumerable fragments of dark brown or black color are found which are sufficiently compact to take a polish, and great numbers of small unit masses are found which have a fissured or septarium-like surface apparently due to expansion by hydration (see plate 56).

In color the oxides range from black to yellow, and the decomposing material frequently shows green discoloration due to the nickel. Some fragments are magnetic, but they all are hydrous and seem to be limonite, with perhaps some turgite.

The metallic centers of the "shale balls" polish and etch as readily as the Canyon Diablo irons, but the crystalline structure is not quite the same, and on exposure they behave differently. The Canyon Diablo retain polished surfaces indefinitely, but the core irons rapidly oxidize in the atmosphere of the laboratory and exude drops of iron chloride, soon giving a fresh coating of rust.

It is evident that we have in association with the crater two varieties of siderites, the well-known Canyon Diablo and the chlorine-rich or oxidizing irons. (For brevity the initials C. D. will hereafter be used for the Canyon Diablo irons and C. D. O. for the oxidizing or decomposing irons.) This is a remarkable and critical fact. Do they represent two distinct falls or are they only variations in the decomposition of one huge meteor? It should also be noted in this connection that two forms of the iron oxides may be distinguished, the limonitic and perishable coatings found on the surface of the oxidizing irons, and the firm, compact, and more permanent form, represented by the fissured nodules. Probably these oxides shade into each other, but nevertheless they must indicate variations in the composition of the meteoric material or different circumstances during the hydration process.

Rock fragments are frequently found cemented together or even enclosed by the meteoric iron oxides, some of the dark and lustrous masses of the latter suggesting fusion, though the form is from solution. The explorers have raised the question if some of the oxide material might not represent the superficial burning of the meteor in its heated flight through the atmosphere, subsequently changed by hydration. Theoretically the fused material on the surface of the flying meteorite is swept away as rapidly as formed, but the particles of oxidized metals which formed the incandescent train of the meteor should be found; and the explorers do find a magnetic dust over the plain, over and through the rock debris, and in the crater drillings to the depth of 650 feet below the



METEOR CRATER NICKEL-IRON OXIDES

Specimens of the individual masses of the harder and less decomposable variety. In size they range from half an inch to 2 or 3 inches

floor of the crater. The association of the meteoric dust with the siderites is an interesting but not unexpected fact which indicates no more association with the origin of the crater than do the large masses, but the incorporation of the meteoric material with the wreckage of the crater and deep in the crushed sandstone of the pit is very significant of an association in time.

Disposition of the Meteor

With expert knowledge of projectiles and their effects Mr Tilghman has discussed the problem of the size of the meteorite which could produce the crater (pages 912–913 of his paper). The effect of a projectile is proportionate to weight and velocity, and with the velocity unknown the weight or size is indeterminable.

The original or planetary velocities of meteors may be very large, many miles per second. Small meteors reach the earth's surface with a low terminal velocity, being checked by the resistance of the atmosphere. A very large meteor with high density would traverse the atmosphere with less loss of energy. It is thought that a siderite with a terminal velocity of only a few miles per second would require a diameter of only a few hundred feet in order to produce the Meteor crater.

The amount of Canyon Diablo irons thus far collected is estimated at about 15 tons. The oxides will add only a few tons to this weight. If we double this to allow for fragments yet distributed in the wreckage on the crater rim, it would amount to, say, 60 tons, or about the weight of the largest known meteorites. But this is only a small fraction of the required weight even under an assumed high velocity, and the explorers reasonably are expecting to find the bulk of the meteor in the depths of the crater.

Mr E. E. Howell long ago suggested (see Doctor Gilbert's article) that, as all the Canyon Diablo irons are perfect individuals, none showing either fracture or friction, they originally were imbedded in some easily decomposed or stony material which has disappeared. It is understood that with the low temperature of the celestial visitors even the nickel iron would be as brittle as glass, and the impact would produce subdivision. The explorers have not been unmindful of this suggestion, but thus far their search has not discovered any stony material foreign to the local rocks. Nevertheless this suggestion may give clue to the fate of the bolide.

A very important factor in the problem of the disposition of the meteor is the behavior of the C. D. O. irons. Their decomposition and disap-

pearance is a very pertinent fact, and no limit can be placed on the amount of this material which has been washed away from the slopes of the crater rim. The flour-like silica is quite impervious to the short rains of that arid region, and the stormwash by the infrequent but powerful downpours carries the fine and soluble materials far out on the plain. In a thousand years an enormous amount of the C. D. O. irons might be removed. The fragments now found on the surface are probably only a few of the more resistant fragments or those lately exposed by the erosion of the slopes. If the C. D. O. irons belong to the same fall as the C. D. irons, then the latter probably represent merely a few unoxidizable fragments from the enormous mass of the wrecked meteor, and a part of the wreck may still lie in the crater.

In conversation with the writer many years ago Mr E. E. Howell said that in his opinion the Canyon Diablo siderites were the most interesting of all known meteorites, because of their number, composition and structure, contents and associations. This judgment has been justified. He also believed that the meteor made the crater and might be partly buried in its depths. He seems to have been correct in the view as to the genesis of the crater, and may yet prove so as to the disposition of the meteor.

In a few months we shall probably know more of this matter, as the explorers are imbued with a persistent and commendable scientific curiosity and intend to continue probing the crater until the drill either finds the meteorite or proves its absence in large quantity. It should be said, however, that failure to find vast amount of the meteoric material in the crater will not be conclusive proof against the meteoric or impact theory of the production of the crater.

Name

The earliest mention in print, by Doctor Foote, of the crater was under the name "Coon Mountain," but the term crater was commonly used in his description, and indeed in most of the writings of later authors.

The name used by Doctor Gilbert was "Coon Mountain" or "Coon Butte."

The San Francisco mountain sheet of the U. S. Geological Survey map designates the feature as "Coon Mt."

Mr Barringer used for his article the title "Coon Mountain and its Crater," while Mr Tilghman used the title "Coon Butte."

The name Coon butte has come into general use, perhaps because of its brevity, euphony, and its non-commital character, but it is wholly

inappropriate and should be supplanted. The mound is not a butte in any sense, having no property of form or structure to which the term is correctly applied. The name mountain is also wide of the mark in referring to a height of only 160 feet.

The adjective name "Coon" is meaningless, for no variety of animal (either carnivore or human) ever known by the name is found in the region. Mr Holsinger has sought to find the origin of the name, but has no clue except that stock men say that it was called "Coon Butte" as a landmark to locate a pool of water some miles eastward, known as "Coon Tank."

The important, striking, and positive topographic feature is not the mound or circular rim, but the depression. The name crater is appropriate with reference to the form, and significant and accurate under either hypothesis of origin, as the term crater is generic, being applied to cavities made by projectiles as well as by explosion. The name is euphonic and is in common use in descriptions of the feature.

As a particularizing adjective the term "Meteor" is entirely appropriate, under either theory of crater origin, on account of its association with the most interesting of known siderites. The reasonably certain conclusion that the crater is the effect of impact adds force to the adjective. Moreover, for some time the U. S. Post Office located near Mr Holsinger's camp with the name Meteor, Arizona, gives an official standing to the word.

The name "Canyon Diablo crater" would not be inappropriate, but it has not the brevity nor the euphony of the name proposed.

Appendix (November 10, 1907)

The above paper gives the status of the Meteor Crater problem at the time of its presentation before the Society, December 29, 1906.

During the past summer the drill has been kept busy in the crater, and the results are summarized as follows in a letter from Mr Tilghman, dated November 1, 1907:

"During the season of 1907 sixteen bore holes have been drilled in the eastern portion of the floor of the crater, to an average depth of between 670 and 880 feet. Thirteen of these bore holes have showed undoubted meteoric material at depths of from 400 to 680 feet below the floor of the crater and in a zone from 20 to 100 feet in thickness. This meteoric material consists of (1) silica powder cemented into greenish lumps with a glassy, slag-like material; (2) a black, vitreous material, both of these containing iron and nickel in large quantities; (3) small grains of native metal containing the same ingredients, supposed to be schreibersite.

"This meteoric material is mixed with the usual filling material of the crater, the crushed debris of the strata penetrated, in the proportion of from a trace to 3 per cent.

"Three of the bore holes have been barren of meteoric material.

"Three of the holes have penetrated the underlying red beds at depths respectively of 830, 860, and 870 feet.

"Fourteen of the holes have certainly, and the remaining two probably, penetrated sandstone apparently in place and almost or entirely unaffected by the shock of the impact which produced the crater.

"No evidence of volcanic activity or hot-spring action whatever has been observed in any of the material penetrated by any of the holes.

"All depths as given above are below the floor of the crater, which is itself about 440 feet below the level of the surrounding plain."

The uncrushed sandstone which was pierced by the drilling, as noted above, has been described as follows in a recent letter from Mr Holsinger:

. . . "as we commenced drilling in the flat northeast of the shaft house we encountered sandstone, solid rock, at about 160 to 200 feet. We have from 250 to 400 feet of this, and then break through into finely crushed sandstone mixed with meteoric material. A great slide of rock seems to have fallen back into the hole. . . . I have secured many cores from this slide, showing that it is unaltered sandstone dipping at an angle of about 40 degrees. This slide covers 4 or 5 acres that we have now explored, and possibly much more."

The following articles have been published during the present year.

George P. Merrill: On a peculiar form of metamorphism in siliceous sandstone. Proc. U. S. Nat. Mus., vol. 32, p. 547.

George P. Merrill and Wirt Tassin: Contributions to the study of the Canyon Diablo meteorites. Smith. Misc. Coll., vol. 50, September 12, 1907, pp. 203-214.

F. N. Guild: Coon Mountain crater. Science, vol. 26, July 5, 1907, pp. 24-25.

These papers develop no facts in opposition to the meteoric theory of the crater genesis. The last mentioned article admits the absence of any visible proofs of volcanism, and fails to note the many facts which support the meteoric hypothesis.

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COMPLEXITY OF THE GLACIAL PERIOD IN NORTH-EASTERN NEW ENGLAND*

BY FREDERICK G. CLAPP

(Read in abstract before the Society December 29, 1906)

CONTENTS

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Manuscript received by the Secretary of the Society from the Censor July 9, 1907.

Introduction

While in the central United States and in Europe the existence of several distinct stages of Pleistocene glaciation separated by interglacial stages has long been recognized, there has been until recently a prevailing belief among geologists that New England was unlike the other northern states, and that it was subjected to but one ice advance and retreat, which has commonly been correlated with the Wisconsin glaciation of the Mississippi valley.

The first suggestion of the possible complexity of the Glacial period came in 1889,* when Shaler published the probability that southern New England at least has been subjected to two ice-advances, separated by a retreat of considerable duration. His conclusions were based on the relations of glacial and interglacial beds at Marthas Vineyard and Nantucket. In 1896 Woodworth† published a description of the clays of southeastern Massachusetts, in which he recognized three glacial stages in southern New England and postulated interglacial stages of considerable duration at least as far north as Boston.

In 1905 Fuller continued the correlations previously established on Long island, New York, along the shores of cape Cod, in eastern Massachusetts, and nearly as far north as Boston.‡

The present paper is an account of scattering observations in northeastern Massachusetts, southeastern New Hampshire, and southern Maine pointing to a similar succession of invasion and drifts in that part of New England.

Literature concerning Evidences of glacial Complexity

From time to time during the past 50 years, and especially during the past 10 years, papers have appeared by various writers describing apparently old till underlying stratified and sometimes fossiliferous deposits in that portion of New England situated northeast of Boston. Most writers believed, however, that the occurrences noted were due merely to brief local retreats and advances of the ice-sheet, and not to any definite interglacial stage.

The earliest reference to interglacial beds appears to be that of Stimpson, who in 1854§ enumerated 14 species of fossils found in a bed of

* N. S. Shaler: The geology of Nantucket. Bull. no. 53, U. S. Geological Survey.

† J. B. Woodworth: The glacial brick clays of Rhode Island and southeastern Massachusetts. Geology and geography of the clays. Seventeenth Ann. Rept. U. S. Geological Survey, part i, pp. 975-988.

‡ M. L. Fuller: Bull. no. 285, U. S. Geological Survey, 1906, pp. 432-433; and "Glacial stages in southeastern New England and vicinity." Science, new series, vol. xxiv, 1906, pp. 467-469.

§ Proc. Boston Soc. Nat. Hist., vol. iv, pp. 9-10.

Figure 1.—*Sketch Map of New England.*

Showing region described in this paper with principal cities and rivers.

stratified clay underlying a drumlin at point Shirley, Winthrop, near Boston, Massachusetts. In 1866 Shaler* described fossiliferous deposits overlain by till at Gloucester, Massachusetts. In 1869 Niles† noted the occurrence of Pleistocene fossils in clay obtained near the bottom of a well 100 feet deep, at Fort Warren, Boston harbor, below 100 feet of drumlin till.

The first and only mention of interglacial soils was the description of a peat bed underlying 20 feet of boulder-clay on river of Inhabitants, Cape Breton.‡ The same occurrence was noted§ in 1878, and gravel underlying till at Saint John, New Brunswick, was also mentioned. In the same year Hitchcock described fossiliferous clays lying between two tills at Portland, Maine,‖ and published sections showing evidence of double glaciation at Tuftonborough, Wolfeborough, New London, New Ipswich, Wilton, Kensington, and Whitefield, New Hampshire.¶ In a chapter of the same report Upham described till resting on stratified clay and sand in the vicinity of lake Winnipiseogee, New Hampshire.**

Ten years later the occurrence of several species of Pleistocene fossils in sand and clay below the drumlin of Great Head, Winthrop, Massachusetts, was noted by Dodge.†† This was near the locality noted by Stimpson in 1854. The occurrence of fossil shells of living species and the evidence of warm climate during their life in the drumlins of Boston harbor, now well known, was first published by Upham in 1888.‡‡ The next year Shaler described several occurrences of blue clay underlying till on Mount Desert island, Maine,§§ and Upham, in his "Structure of drumlins," described a number of instances of stratified sand and gravel underlying drumlins in the vicinity of Boston.‖‖ In 1890 Chalmers described stratified clay below till at Nogrotown point, New Brunswick,¶¶ and in 1893 he described this occurrence more fully.***

The occurrence of fossils in the drumlins of Boston harbor, first de-

* Notes on the position and character of some glacial beds containing fossils at Gloucester, Massachusetts. Proc. Boston Soc. Nat. Hist., vol. xi, pp. 27-30.

† W. H. Niles: Proc. Boston Soc. Nat. Hist., vol. xii, pp. 244, 364.

‡ J. W. Dawson: Canadian Naturalist, second series, vol. vi, 1872, p. 178.

§ Supplement to the second edition of Acadian Geology, pp. 27-28.

‖ C. H. Hitchcock: Geology of New Hampshire, vol. iii, pp. 279-282.

¶ Op. cit., pp. 290, 311.

** Op. cit., pp. 131-138.

†† W. W. Dodge: Am. Jour. Sci., third series, vol. xxxvi, 1888, pp. 56-57.

‡‡ Warren Upham: Marine shells and the fragments of shells in the till near Boston. Proc. Boston Soc. Nat. Hist., vol. xxiv, pp. 127-141.

§§ Eighth Ann. Rept. U. S. Geological Survey, pp. 998-999.

‖‖ Proc. Boston Soc. Nat. Hist., vol. xxiv, 1889, p. 237.

¶¶ Robert Chalmers: Report on the surface geology of southern New Brunswick. Geol. and Nat. Hist. Survey of Canada, Report N, p. 24.

*** Height of the Bay of Fundy coast in the Glacial period relative to sealevel, as evidenced by marine fossils in the boulder-clay at Saint John, New Brunswick. Bull. Geol. Soc. Am., vol. 4, pp. 361-370.

scribed by Upham, was best set forth by Crosby and Ballard in 1894.* In 1896, in connection with a discussion of the "Glacial brick clays of Rhode Island and southeastern Massachusetts," Woodworth described the "Geology and geography of the clays,"† in which he postulated three glacial stages separated by interglacial stages. In the same report Marbut and Woodworth described "The clays about Boston" and published many sections and other evidences of till overlying the clays.‡

An account of the geology of the Cape Cod district was given by Shaler in 1898,§ in which he followed Woodworth in his general outline of Pleistocene succession and described many occurrences of folded sands and clays, till overlying clays and sands, and other evidences of glacial complexity.

In 1899 Stone, in his "Glacial gravels of Maine and their associated deposits," gave a number of evidences of probable pre-Wisconsin deposits, but did not interpret the phenomena in this way.‖

While several observers had described differences in the tills of New England which in the light of our present knowledge would seem to indicate differences in age, up to 1901 all geologists except Woodworth had assumed them to simply represent stages of a single invasion, the Wisconsin. In that year, however, Fuller,¶ in discussing the region in the vicinity of Brockton and Stoughton, a short distance south of Boston, pointed out the existence of two distinct tills characterized by marked differences in composition and weathering, which he definitely stated were the representatives not of a single glacial epoch, as had previously been assumed, but of two widely separated epochs, the Wisconsin and the Kansan or pre-Kansan. Examples of deep weathering and disintegration of rock ledges between the two epochs were also described.

Continuing along the lines of investigation begun by Woodworth, Brown, in 1902,** described a number of cases of till overlying sand and clay in Everett, Chelsea, and Revere, near Boston.

In 1903 the term "interglacial" was questionably applied by Tarr to some fossiliferous beds at cape Ann,†† not far from the locality described by Shaler 40 years before.

* W. O. Crosby and Hettie O. Ballard: Am. Jour. Sci., third series, vol. xlviii, pp. 486-496.

† Seventeenth Ann. Rept. U. S. Geological Survey, part i, pp. 975-988.

‡ Op. cit., pp. 989-1004.

§ Eighteenth Ann. Rept. U. S. Geological Survey, part ii, 1898, pp. 503-593.

‖ Geo. H. Stone: Monograph 34, U. S. Geological Survey, 1899.

¶ M. L. Fuller: Probable representatives of pre-Wisconsin till in southeastern Massachusetts. Journal of Geology, vol. 9, pp. 311-329.

** R. M. Brown: The clays of the Boston basin. Am. Jour. Sci., fourth series, vol. xiv, pp. 445-450.

†† R. S. Tarr: Postglacial and interglacial (?) changes of level at Cape Ann, Massachusetts. Bull. Harv. Coll. Mus. Comp. Zool., vol. xlii, pp. 181-191.

Crosby, in his Report to the committee on the Charles River dam,* notes a number of cases of sands and clays locally interstratified with till. Several sections in which till overlies fossiliferous and other clays in northeastern Massachusetts were given by Sears† in the "Geology of Essex county, Massachusetts." The latest contribution is by Fuller,‡ who in 1906 not only again correlates the earliest tills of the Brockton region with the pre-Kansan, but refers the drumlins about Boston, with few, if any, exceptions, to the Illinoisan, assigning only the thin, loose, and relatively unoxidized surface tills to the Wisconsin.

Although the number of references to phenomena indicative of more than one glacial stage in northeastern New England is large, there has been no attempt, except by Woodworth and Fuller, to correlate the deposits, or even to formulate conclusions, most writers adhering steadfastly to the belief that the phenomena were caused simply by local retreats and advances of the Wisconsin ice-sheet.

Fieldwork and Acknowledgments

In 1905 the present writer had the privilege of being associated with Mr M. L. Fuller in Pleistocene investigations in New England south of Boston, and obtained many data in that region which throw light on the problem in hand. In 1906 he was assigned to work in Maine and in northeastern Massachusetts and southeastern New Hampshire for the Water Resources branch of the U. S. Geological Survey, and in that connection had opportunity to observe many Pleistocene phenomena north of Boston. For a part of the data here presented he is indebted to Mr George C. Matson, who assisted him in the underground water investigations. He also wishes to express his thanks to Mr Fuller for many useful suggestions and criticism of the manuscript, and to Dr W. H. Dall for supplying the most modern names of the fossils found in the marine clays.

Results

The writer is of the opinion that many of the phenomena observed can be explained in but one way—by the invasion of New England by at least three ice-sheets, separated by time intervals of long duration. On account of the greater thickness of the drift and because of fewer exposures, due

* A study of the geology of the Charles River estuary and the formation of Boston harbor, in "Report of the committee on the Charles River dam." Boston, 1903, pp. 345-369.

† J. H. Sears: Salem, Massachusetts, 1905, pp. 357 et seq.

‡ M. L. Fuller: Science, new series, vol. 24, pp. 467-469.

to the rocky nature of the coasts and the less settled condition of the region, many difficulties are found in the solution of Pleistocene problems that are not found farther south. In northeastern New England a careful search for exposed sections is necessary, and most of those found are poor. The nature of the writer's work did not permit him to spend much time hunting for exposures, and the facts here presented are therefore but a small part of the evidence which might be collected by systematic field studies on this problem. Absolute correlations are not yet possible, and such as are here presented should be considered merely in the nature of suggestions, as showing what appears to be the most probable age of the various deposits. The observations thus far made and the conclusions derived from them are given with the hope that they may be of some assistance to future investigators along this line.

Classes of Evidence

The evidences which indicate the complexity and succession of Pleistocene deposits in northeastern Massachusetts, southeastern New Hampshire, and southern Maine are as follows:

1. The occurrence of old tills differing in structure, relations, and composition from the more common and superficial types of till.
2. Evidences for the differentiation and correlation of the so-called "Leda clay."
3. Differences in distribution and topography of the clays.
4. Erosion unconformities representing time intervals.
5. Till and morainal deposits overlying marine clay and stratified sand.
6. Folding and erosion of stratified sand, clay, and gravel deposits which must have been originally horizontal, and modification of clay surfaces by overriding ice.
7. Different degrees of oxidation and weathering of the deposits.
8. Buried soil zones.

Pleistocene Succession

In order to give a good idea of the relations of the different types of deposits described in the following pages, a tabulated summary is here presented, with the possible correlations. The correlations with southeastern Massachusetts are probably correct, and those with the deposits described by Fuller and Veatch on Long island are probably approximately correct, but those with the Mississippi valley are simply postulated. In these latter correlations the writer has followed Fuller and Woodworth.

Descri
northeas
Moraines an gravel de tributed.
Clays, sand outwash feet thick)
Thin till, n kames (0 t
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Coarse strati gravels (10
Till (includi 300 + feet
Stratified sa feet thick)
Stratified cla
UNCONFORMI
Very old till
UNCONFORMI

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Table of Pleistocene Deposits and Possible Correlations.

Description of deposits in northeastern New England.	Names used in this part of New England.	Probable altitude of land relative to present sealevel (feet).	Possible correlations. Fuller. Southeastern Massachusetts.	Woodworth. Southeastern Massachusetts.	Fuller. Long island and Fishers island.	Veatch. Long island.	Calvin, Chamberlin, and others. Mississippi valley.
Moraines and irregular sand and gravel deposits irregularly distributed.	Local post-Wisconsin glaciation.		Not represented.	Not represented.	Not represented.	Not represented.	Probably late Wisconsin.
Clays, sand and gravel deltas and outwash deposits (0 to 100 + feet thick).	Wisconsin retreatal deposits.	— 100	Wisconsin retreatal deposits.	Champlain.	Wisconsin outwash.	Wisconsin outwash.	Wisconsin retreatal deposits.
Thin till, moraines, eskers, and kames (0 to 20 feet thick).	Wisconsin.		Wisconsin till.	Third glacial.	Wisconsin till.	Wisconsin till.	Wisconsin till.
Unconformity.		+ 60 +	No deposits recognized; mainly period of erosion.	Vineyard interval.	Period of erosion.	Tisbury (Manhasset).	Peorian.
Extensive deposit of fossiliferous marine clay, with some associated sand.	"Leda clay."	— 0 at Boston to — 250 in Maine.					Iowan till.
Unconformity.		(?)					Sangamon.
Coarse stratified and unstratified gravels (100 + feet thick).	(Unnamed.)	— 100	Unnamed sand.	Tisbury.	Upper part of Manhasset.	(Placed in Iowan.)	Illinoisan.
Till (including drumlins) (20 to 300 + feet thick).	Montauk.	— ?	Montauk drift.	Gay Head interval.	Montauk till.	Not recognized.	
Stratified sand and gravel (10 + feet thick).	(Only exposed at few points on the coast.)	— 10 ±	Herod gravel.		Herod gravel. (Lower Manhasset.)	(Placed in Iowan.)	
Stratified clay (a few feet).	(Only exposed at Winthrop, Mass.)	— 10 ±	Gardiner clay.	Sankaty.	Jacob sand. Gardiner clay.	Sankaty.	Yarmouth.
Unconformity.		+ 200 +			Jamico gravel.	Jamico gravel.	Kansan.
					Erosion unconformity.	Erosion unconformity.	Aftonian.
Very old till.	(Unnamed.)		Mannetto (?).	Not recognized.	Mannetto gravel.	Mannetto gravel.	Pre-Kansan.
Unconformity.		+ 400 +			Erosion unconformity.	Erosion unconformity.	
					Cretaceous clay.	Cretaceous clay.	

Detailed Descriptions

EROSION OF DEEP ROCK VALLEYS

Description.—Borings made near the coast in all the large valleys entering the Atlantic between New York and central Maine have shown that the bed-rock floor underlying the drift is very irregular, and that buried valleys extend inland often for many miles, and some of them bear little relation to the direction and distribution of the present streams.

The buried gorge of Hudson river at New York is known to be at least 300 feet deep below the present sealevel,* and its course has been traced over 100 miles out to sea in the form of a deep canyon-like gorge several thousand feet deep.† Recent borings by the New York commission on additional water supply in the Hudson river near West Point are reported by the engineers to show that the valley floor at that place is 450 feet or more deep below tide.

Numerous wells and borings sunk at Boston have shown that the bed-rock floor of the ancient rivers at that city lies 200 to 400 feet in maximum depth below the present sealevel.‡ Wells of the Amesbury water works, situated on the banks of Merrimac river 6 miles from its mouth, strike rock at 100 feet below sealevel, and the wells of the Salisbury Beach water works go nearly to that depth without striking rock. Across Fore river, between Portland and South Portland, Maine, a line of borings has been made which shows a bed-rock valley 110 feet in maximum depth below tide. Test borings made for the Brunswick-Topsham water district on the banks of Androscoggin river at Brunswick struck rock at 155 feet.

Age of erosion.—It is commonly supposed that these old gorges were eroded during the continental elevation immediately preceding the first recorded ice invasion, but in most of them there is no known reason why the erosion may not date from the Aftonian or even the Yarmouth interglacial stage. According to Fuller, the evidence on Long island indicates that the main erosion of the Hudson River channel was subsequent to the deposition of the Manetto gravels (page 516), and in all probability antedated, in part at least, the deposition of the Kansan materials there; hence the principal work of erosion was presumably Aftonian. In all the valleys the erosion far antedates the Montauk or principal stage of

* W. H. Hobbs: The configuration of the rock floor of Greater New York. Bull. no. 270, U. S. Geological Survey, 1905, p. 41.

† J. W. Spencer: Submarine great canyon of the Hudson river. American Geologist, vol. xxxiv, 1904, pp. 292-293.

‡ F. G. Clapp: Geological history of the Charles river. Technology Quarterly, vol. xiv, 1901, pp. 171-201; American Geologist, vol. xxix, 1902, pp. 218-233.

W. O. Crosby: Report of the committee on the Charles River dam, Boston, 1903, pp. 345-369, and earlier papers.

glaciation (see page 524), and the fact, recorded elsewhere, that a marked continental elevation took place in pre-Kansan time indicates that some of the valleys probably date back to the close of the Tertiary period.

OLD TILLS

General statement.—In the year 1905 certain deposits of till in Brockton and Stoughton, Massachusetts, were described.* The deposits were found in excavations underneath the ordinary surface till of the region, were very different in character from the surface till, and were definitely assigned to Kansan or pre-Kansan age.

In 1899 Stone described several feet of a "hard, tough clayey till that resisted erosion wonderfully, and broke up into blocks 2 or 3 feet in diameter" on Penobscot river, at the mouth of South Twin lake, in central Maine.† "Above this was a lighter-colored and less compact till forming a north-south ridge or elevated drumlin." Stone discussed the possibility of the lower of these two deposits being an old till, but for some reason decided that it was only a phase of the Wisconsin.

With these two exceptions, no descriptions of old tills in New England are known to have been published. The present writer has not seen these, but has noted a number of similar exposures of till which can hardly be explained except on the supposition that they are very old.

Exposure at South Norridgewock, Maine.—On the road leading down to Kennebec river from the village of South Norridgewock there is an 8-foot section of "old-looking" till, oxidized very yellow and brown from top to bottom. For a foot or two at the top the material is ordinary till composed of moderately fresh and polished pebbles, mostly of foreign origin. The rest of the section is nearly as hard as rock, standing perpendicular and being very firm and tough. It consists largely of pebbles less than a foot in diameter, and most of the fragments are dark sandy slate, but some are quartzite. Many are angular, but some are well rounded. A few are striated. The till is very clayey and the clay sticks firmly to the pebbles. The mass is somewhat iron-stained and the iron takes some part in the process of cementing. So far as could be determined from a brief examination, the deposit does not contain any granite pebbles. The relation to other deposits than the superficial till could not be determined.

Section at South Lawrence, Massachusetts.—A cut exposed in 1906 along the Boston and Maine railroad at South Lawrence, Massachusetts, showed the section illustrated in figure 2.

* M. L. Fuller: Journal of Geology, vol. ix, pp. 311-329.

† Monograph no. 34, U. S. Geological Survey, p. 285.

The bed-rock at this place is a metamorphic schist, on which rests 4 to 12 feet of a hard, much oxidized, bright yellow till, made up largely of the underlying schist, but containing some foreign pebbles. Overlying it are 1 to 5 feet of a somewhat oxidized till containing numerous foreign pebbles. Above these tills is a stratum of 2 to 5 feet of fine white sand which has been considerably contorted, evidently by the weight of overlying ice, which deposited 1 to 6 feet of clayey and bouldery till which forms the surface. The surface deposit is oxidized for about 2 feet at the top.

The lowermost drift deposit in this section has the appearance of a very old till, its difference in character, its high degree of oxidation, and its position indicating that it was not deposited by any slight oscillation of the Wisconsin ice front. The same beds were seen in a cellar excavation near by.

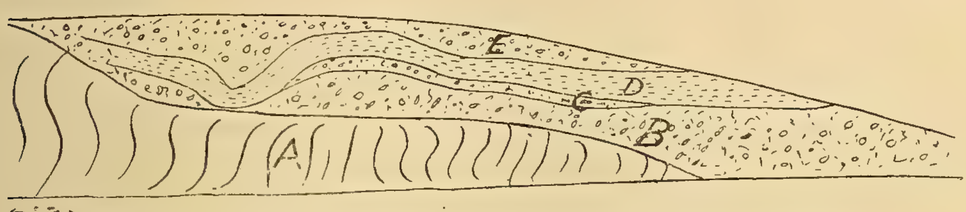

FIGURE 2.—*Section in Railroad Cut at South Lawrence, Massachusetts.*

Showing deposits of old till. A, bed-rock; B, hard, much oxidized till, made up largely of underlying schist; C, somewhat oxidized till containing many foreign pebbles; D, fine white sand, with contorted stratification; E, clayey, bouldery till, oxidized about two feet at the top.

Exposures at Portland, Maine.—In a sand pit one-fourth of a mile north of Union station, Portland, there are extensive exposures of sand and gravel overlain by clay. At one point here a peculiar feature was exposed in June, 1906. This is illustrated in figure 3. The hard, compact, light gray to dark brown, blocky clay rested on an unconformity, below which was 3 feet or more of a horizontally stratified glacial sandstone containing a few boulders, mostly of similar material, up to 2 feet in diameter. The sandstone was very solid and resistant, cemented by iron oxide. Below this occurred 2 feet of stratified sand and fine gravel, oxidized very yellow and resembling certain yellow sands seen in connection with pre-Montauk drift underneath drumlins at Scituate and Plymouth, Massachusetts. The pebbles in this bed were much decomposed by weathering, only those composed of quartzite remaining solid. The only granite pebble that could be found was 2 inches in diameter and was stained to the center. The weathering and erosion of the sands before the deposition of the clay indicate an intervening elevation of some duration. A thorough search was made for another and better exposure of the deposit, but none could be found.

Other exposures.—Several exposures which resemble old till were observed in the southern part of Gardiner, the southern part of York, and on Mount Desert island, Maine; at Newton, New Hampshire; and near Canton Junction, Haverhill, and under North Ridge at Ipswich, Massachusetts, and elsewhere. In the towns of Paris and Rumford, Maine, a number of road exposures of a hard, compact type of till were seen, which is very dark in color and of a shaly texture, unlike till seen anywhere else in Maine. In some exposures it is possible that the high colors and old appearance may be due to staining by iron; in others this is clearly not the case. Nearly all these tills occur in depressions in the bed-rock where they have evidently been protected from erosion. The Norridgewock and Portland exposures are exceptions to this statement.

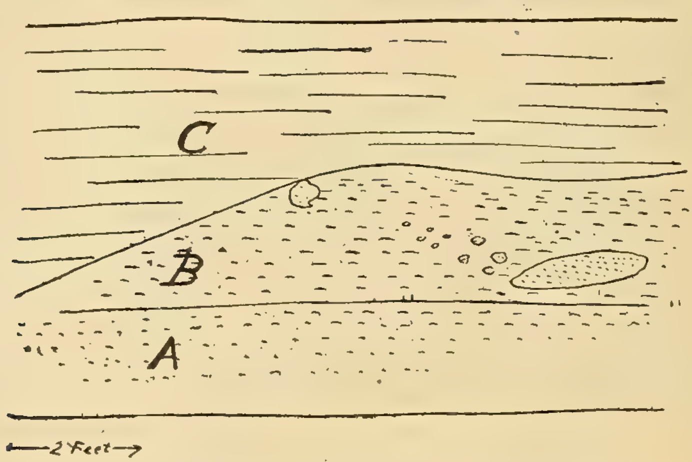

FIGURE 3.—*Section of Gravel Pit at Portland, Maine.*

Showing evidences of probable old drift. A, horizontally stratified sand, affected by weathering; B, sandstone, contain a few boulders; C, hard, unweathered clay, resting unconformably on B.

Correlations.—These old deposits may not all be of identical age, and no data are at hand by which to judge of their exact age. They are probably as old as the Manetto gravels of Long Island* and the Kansan or pre-Kansan till of the middle West. These tills are distinguished from the next more recent till (Montauk) by the following characteristics:

1. By the greater abundance of pebbles of the underlying bed-rock than of rock from a distance.

2. By the greater abundance of pebbles of rock not easily decomposed (that is, slate and quartzite) and the absence of decomposable pebbles.

3. By their deeper oxidation and brighter colors.

4. By their occurrence underneath more recent till.

* M. L. Fuller: Geology of Fishers island, New York. Bull. Geol. Soc. Am., vol. 6, 1905, pp. 373-375.

5. By their occurrence on the immediate surfaces of the pre-Glacial bed-rock and usually occupying depressions in it.

UNCONFORMITY SUCCEEDING DEPOSITION OF OLD TILLS

The old tills are found only locally, indicating that they were extensively eroded before the deposition of the overlying drifts. The stage of erosion must have been a long one, and created a great gap in the Pleistocene record, about which nothing is known, as no contact has been found between the tills and the next succeeding deposits. If the old till is of pre-Kansan age, the erosion may have extended from the Aftonian to the Yarmouth stage. If the till corresponds to the Kansan, the erosion came in Yarmouth time. It is possible that this stage of unconformity was the time during which some of the deep river gorges of the New England coast were eroded. As stated on page 513, the principal erosion of the Hudson valley presumably took place at this time.

GARDINER CLAY

General statement.—With the exception of the ancient tills, the oldest deposit recognized north of Boston consists of stratified clay exposed underlying the drumlins at Winthrop, Massachusetts, and described by Stimpson in 1854.* In the blue clay at that locality 14 species of fossils were found and are listed in column 4 of the table (page 520).

Dodge, in 1888, found strata of sand and clay outcropping below Great head in the same town, and collected the species of fossils noted in column 5. Upham, in the same year, found fossils in a stratum of blue clay under Grovers cliff, in the same town, and this exposure was seen and verified by the present writer in 1905.

Relations and correlations.—In none of the three cases noted above can the base of the clay be seen. In all three cases the stratified deposits are overlain by the hard boulder-clay of the drumlins, rising to heights of over 50 feet above tide. The clay found below the drumlins is believed to be of the same age as the Gardiner clay described by Fuller,† and to date from the "Sankaty" sub-epoch of Woodworth.‡

Distinction from other clays.—This clay is distinguished from Tertiary clay by its color, by its general appearance, and by its fossils. It is distinguished from more recent clays by being overlain by drumlin till (Montauk). The fact that the till of the drumlins in Boston harbor contains large numbers of fossil shells§ of the same and similar species

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* Proc. Boston Soc. Nat. Hist., vol. iv, pp. 9-10.

† Bull. Geol. Soc. Am., vol. 16, 1905, pp. 375-378; Bull. no. 285, U. S. Geological Survey, 1906, p. 433.

‡ Seventeenth Ann. Rept. U. S. Geological Survey, 1896, p. 966.

§ Upham: Proc. Boston Soc. Nat. Hist., vol. xxiv, 1888, pp. 127-141.

to those found in the Gardiner clay indicates that they were scooped up with their clayey matrix from a deposit of Gardiner clay which in pre-Montauk time was more extensive in Boston harbor than at present. In a few cases masses of Gardiner clay several inches in size have been found incorporated in the drumlins.

Evidence afforded by fossils.—At the beginning of this investigation it was not supposed that fossils would afford any evidence for correlation or distinction between formations within the New England Pleistocene. In order to get together all classes of material which might be of value, however, the various papers referring to the Pleistocene geology of this part of New England were consulted and the lists of fossils tabulated. To bring the names of the species up to date, the lists were referred to Doctor W. H. Dall, of the U. S. Geological Survey, with the request that he correct the names of the species in cases where the usage has changed since the time the respective papers were published. The writer is indebted to Doctor Dall for making the corrections and putting the specific names in such form that the lists could be revised and the species arranged in alphabetical order in the table. The writer alone is responsible, however, for the arrangement and the attempts at correlation. The table is on pages 520–523.

When the table was completed there was seen to be a striking contrast between the first six columns and the other columns in species enumerated. Of the 20 species found in and near Boston harbor (columns 2–6), only 8 were found to occur north of Winthrop. Of these 8, only 2, namely, *Mya arenaria* and *Mytilus edulis*, are found in more than one locality elsewhere, and these 2 are found in 9 and 7 other localities respectively.

A still greater contrast is found between the species from Lynn, Danvers, and Gloucester, Massachusetts, and those from Boston harbor. Of the 17 species from those three localities, within 10 to 20 miles north of Boston, not a single species is found in any of the Boston Harbor localities. Two of the species enumerated in the table, namely, *Venericardia borealis* and *Venus mercenaria*, are found in all five of the Boston localities, but are not found elsewhere.

In order to compare the conditions south of Boston with this discrepancy, the species from the Gardiner clay on Gardiners island, New York (column 1), were compared with those at Boston. Of the 8 species enumerated from Gardiners island, 4 were found near Boston, and only 2, *Chrysodomus decemcostatus* and *Thracia conradi*, occur north of Boston. These are found only at Portland and Biddeford respectively.

If any correlation by fossils were possible, it would seem, on the basis of these comparisons, that the clays found beneath the Winthrop drumlins and those incorporated in the drumlins of Boston harbor were of different age from the clays at Lynn, Danvers, and at other points north of Boston, and that those at Lynn and Danvers might be the same as those on the coast of Maine. Packard* describes the geographic range of the various species, and states that the difference between the fauna north and south of cape Ann is due to the difference in climate at the time the clays were deposited, and assumes that the marine clays are all of the same age. On the basis of stratigraphic evidence this does not seem to be true. Moreover, the change in species is not at cape Ann, but between Boston and Lynn, and between these two localities there was no barrier nor other geographic feature sufficient to separate a temperate from an arctic fauna. Hence the conclusion that the clays north and south of Lynn are of different age seems well substantiated, the former, as will be shown in a subsequent section, being younger than the drumlin till, while the latter are older.

The data do not enable us to distinguish between the two clays on the Maine coast, nor do they throw any light on the age of the Cambridge and Revere clays, as these latter do not contain fossils.

STRATIFIED SAND AND GRAVEL

Although clay of Gardiner age north of Boston is exposed only at Winthrop, one case has been observed where stratified sand and gravel underlie a drumlin. This was at Little Boars head, New Hampshire, which is a drumlin-like hill, on the seaward face of which the following section was seen:

Section at Little Boars Head, New Hampshire

	Feet
C. Sandy and bouldery till, Wisconsin	1 to 8
B. Hard vertical till, clayey, bouldery, Montauk	10 to 20
A. Patch of horizontally stratified sand and gravel 100 feet long	6

This may simply be a case of local interstratification of gravel in a drumlin, or the deposit may be analogous to the Herod gravel which overlies the Gardiner clay and underlies the Montauk drift on Long island. Considering the size and horizontal stratification of the deposit, the latter supposition is more probably the true one.

* A. S. Packard: Observations on the glacial phenomena of Labrador and Maine. Mem. Boston Soc. Nat. Hist., vol. 1, 1865, pp. 210-303.

Species.	1 Gardiner clay on Gardiner's island, New York (Veatch).	2 Islands in Boston harbor, fossils from till (Upham).	3 Under Fort Warren, Boston harbor (Niles).	4 Under point Shirley, Winthrop (Stimpson).	5 Great head, Winthrop (Dodge and Upham).	6 Under Grovers cliff, Winthrop (Upham).	7 Graham brick-yard, Lynn (Sears).	8 Carr brick-yard, Danvers (Sears).
Amauropsis islandicus Gmel.								
Astarte banksii Leach								
" *borealis* Schum.								
" *castanea* (Say)				×	×			
" *elliptica*								
" *striata* Leach								
" *sulcata*				×				
" *undata* Gould	×				×	×		
Asterias stellionura Poiret								×
" *vulgaris* Stimps								
Asterocanthron lincki Mühler								×
Balanus balanoides								
" *crenatus*					×			
" *hameri*								
" *porcatus* Da Costa								
" *rogusus*				×				
Bos americanus Gmel								
Buccinum glaciale Linn.								
" *grönlandicum* Hancock								
" *plectrum* var. *packardi* Stimps								
" *tenue* Gray								
" *totteni* Stimps								
" *undatum* L.								
" " var. *undulatum*								
Cancer borealis Stimps								
Cardium ciliatum Fabr.								
" *islandicum*					×			
" *pinnulatum* Conr.								
Chrysodomus decemcostatus Say	×			×	×			
" *despectus* L.								
Citenofasus pygmæus Gould	×							
Cliona sulphurea (Verrill)					×	×		
Crenella arca	×							
Cylichna oryza Stimpson								×
Cyprina islandica (Gmelin)	×							
Ensis directus Conrad				×	×			
Eschara elegantula D'Orb.								
Eupogurus bernhardus Stimps.								
Haminea occulta Mighels								
" *solitarea* (Say)								×
Hyalina var. *danversiensis* Sears								
Hyas aranea (Linn)								
Idmonea atlantica (*I. pruinosa*) Stimp.								
Lacuna neritoidea (Say)					×			
Leda arctica								
" *buccata* Sternstrup								
" *tenuisulcata* Couth.								
Lepralia annulata (Fabr.)								
" *hyalina* Linn.								
" *nitida* (Fabr.)								
" *variolosa* Johnst.								
Liocyma heros (Say)								
Lunatia heros (Say)	×		×					
Lyonsia arenosa Morch							×	

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Species.	1 Gardiner clay on Gardiner's island, New York (Veatch).	2 Islands in Boston harbor, fossils from till (Upham).	3 Under Fort Warren, Boston harbor (Niles).	4 Under point Shirley, Winthrop (Stimpson).	5 Great head, Winthrop (Dodge and Upham).	6 Under Grovers cliff, Winthrop (Upham).	7 Graham brick-yard, Lynn (Sears).	8 Carr brick-yard, Danvers (Sears).
Machæroplox cinereus Gould								
Macoma balthica Linn								
" " var. *grönlandica* Beck								
" *calcarea* (Gmel.)								
Mallotus villosus Cuvier								
Menestho albula Möll								
Membranipora americana D'Orb								
Mesodesma arctata								
Modiolaria discors (L.)								×
" *lævigata* Gray								×
" *nigra*								
Modiolus modiolus Linn				×	×			
Mya arenaria (Linn.)				×	×			
" *truncata* Linn								
Mytilus edulis (Linn.)				×	×			
Natica clausa Sowb								
" (*Lunatia*) *grönlandica* Beck								
Nucula expansa Reeve								
" *tenuis* (Mtg.)								
Ostrea virginica Gmelin				×	×			
Pandora (*Clidrophora gouldiana* Dall							×	
Panomya arctica Gould								
Pecten (*Chlamys*) *islandicus* Linn								
" (*Pseudomuscum*) *grönlandicus* Sowb								
" *islandicus* Müller								
" *magellanicus* (Gmelin)	×							
Perpusa lapillus								
Pholas crispata Linn								
Rosmarus obesus Illiger								
Saxicava arctica (*Deshayes*) = *S. distorta and S. rugosa*							×	×
Schizoporella hyalina Linn								×
" " var. *danversiensis*								×
Serripes grönlandicus Beck								
Spilorbis nautiloides Lamk								
Spisula polynyma (Stimpson)								×
" *solidisima* Dillwyn				×	×			
Stomatopola expansa Pack								
Strongylocentratus drobachiensis (Möll.)								
Thracia gouldii								
" *conradi* Couthony	×							
" *truncata* Mighels and Adams								
Tritia trivittata Say				×	×			
Tritonofasus kroyeri Beck								
" *pygmæus* Gould								
Urosalpinx cinereus (Stimpson)				×	×			
Venericardia borealis Conr		×	×	×	×	×		
Venus mercenaria L.		×	×	×	×	×		
Yoldia glacialis (Wood)							×	×
" (*Portlandica*) *lucida* Loven								×
" *mytalis* Couth								
" *pygmæa* Münster								
" *sapotilla* (Gould)								

9 Gloucester (Shaler).	10 Wibirds hill, Portsmouth, N. H. (Hitchcock).	11 Kittery, Maine (Hitchcock).	12 Saco (Hitchcock, Packard).	13 Portland (Hitchcock, Packard).	14 Westbrook (Hitchcock, Packard).	15 Islands of Casco bay (Pack-ard).	16 Brunswick (Packard).	17 Lewiston (Packard).	18 Gardiner (Packard).	19 Augusta (Packard, Atkins).	20 Waterville (Packard, Loomis).	21 North Haven (Packard, De Laski).	22 Bangor (Packard).	23 Eastport (Packard, Verrill).	24 Campo Bello (Packard).	25 Nogrotown point, New Brunswick (Chalmers).
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PRINCIPAL TILL DEPOSIT (MONTAUK)

General description.—The principal till deposit of New England includes a large part of the drift which has hitherto been called Wisconsin. It is in most places a very hard blue boulder-clay containing many striated and angular stones and boulders which are in places many feet in diameter. The material is very stiff, and when dug into will stand nearly as well as rock. When water-worn, as in drumlin sections along the shore, it is eroded into deep gullies, and the shores round the base of the section are strewn with boulders. This till ranges in thickness from a few feet to several hundred feet, where it is thickened up into drumlins. The latter are very numerous in Massachusetts and New Hampshire. As a rule, along the coast the till is perceptibly yellow from the effects of oxidation to a depth of 15 to 20 feet from the surface, below which the characteristic unoxidized blue-gray till is found.

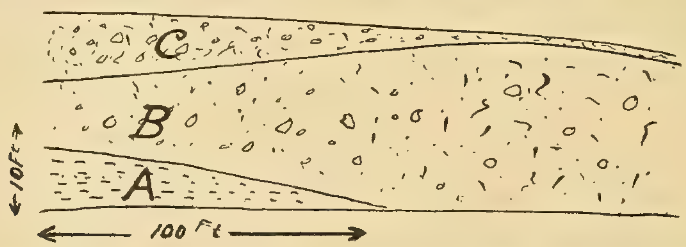

FIGURE 4.—*Wave-cut Section at Little Boars Head, New Hampshire.*

Showing two tills and underlying stratified deposit. A, sand and gravel; B, hard, vertical till, Montauk; C, sandy and bouldery till, Wisconsin.

Relation to other deposits.—The principal till deposit in northeastern New England overlies the Gardiner-Herod clay and gravel wherever these have not been removed by erosion. The till is overlain nearly everywhere in the lowlands by stratified deposits of sands, gravels, and clays of Wisconsin and pre-Wisconsin age. Hence the till is believed to be Montauk. This is the correlation made by Fuller on Long island and cape Cod, and to him belongs the credit of demonstrating the Montauk (possibly Illinoisan) age of the drumlins in the vicinity of Boston.*

Evidence that this till is not Wisconsin in age.—The evidence that the principal till sheet, hitherto called "Wisconsin," with its drumlins, belongs in reality to an earlier ice-invasion is fourfold:

1. It appears to extend from Long island, New York, where its relations are well established and exposed, almost continuously to the drumlins of Boston harbor.

2. It is overlain by fossiliferous marine clays, which are in turn overlain by another till deposit (Wisconsin).

* Science, new series, vol. 24, 1906, pp. 467-469.

3. It is far more deeply oxidized by weathering than the latest till.

4. Numerous sections show both this and a more recent overlying till of different character and relatively slight weathering.

1. Tracing from Long island.—On Long island and vicinity Fuller* found the Gardiner clay widely distributed beneath the Montauk drift, the latter being overlain by stratified sands and gravels, and these in turn by Wisconsin till. The Gardiner clay was later traced from Long island along the south and north shores of cape Cod, where it has similar relations to the till.† The last exposure south of Boston is at Indian hill, Plymouth, where the same relations hold true. North of there the clay is either below sealevel or it has been eroded, for at Saquish head, Duxbury, and Third cliff, Scituate, the drumlins visibly overlie more ancient deposits.‡ These sections have been examined by the writer, and only traces of the clay have been found at the base of the drumlin till. The latter is in lithologic characteristics like the till overlying the Gardiner clay at Indian hill, Plymouth; hence it would appear that this till is of Montauk age.

2. Relations to overlying clays.—The Montauk till is overlain by fossiliferous marine clays that are in turn overlain by a younger till. The farthest point south where clay has been observed overlying till is at Warren cove, Plymouth. In the vicinity of Boston and in the region northeast of that city the localities where clay can be seen to overlie the principal till deposit of the region are so numerous as to need no individual mention. These may be found in numerous brick-yards, wells, and road cuts. From Lynn northward the post-drumlin clay is fossiliferous and has been known as the "Leda clay." In many places north of Boston it can be seen to be overlain by a still more recent till (Wisconsin), as explained on pages 544-552.

3. Degree of oxidation.—While degree of oxidation is not absolute proof of the age of any deposit, it furnishes an indication of the relative ages of deposits of similar texture. A till deposit oxidized to the depth of 10 feet is, other things, such as composition and texture, being equal, probably much older than a similar till oxidized only 2 feet. The same statement will hold true relative to clays and, to a more limited degree, of sand deposits.

The general depth of oxidation (surface yellowing) in the more recent (Wisconsin) till, as exposed in sections widely scattered through north-

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* Bull. Geol. Soc. Am., vol. 16, 1905, pp. 367-390.

† Bull. no. 285, U. S. Geological Survey, pp. 432-441; Science, new series, vol. xxiv, 1906, pp. 467-469.

‡ I. Bowman: Pre-Pleistocene deposits at Third cliff, Massachusetts. Am. Jour. Sci., vol. xxii, 1906, pp. 313-325.

east New England, is 2 to 5 feet (pages 547-548). The Montauk till in the vicinity of Boston harbor, in Revere, in the Merrimac valley, and in Maine is, however, perceptibly yellowed to a depth of 15 to 20 feet from the surface, notwithstanding it is far more compact and impervious to percolating waters. This can be well seen in the fine drumlin sections in Boston harbor and vicinity.* Another good place to observe the weathering in this type of till is in a cut on the western side of Long hill, in West Newbury, Massachusetts, where Merrimac river at some recent date got out of its channel and cut a side valley, now abandoned. The yellowish upper portion of the till, here 15 feet deep, is in marked contrast to the blue till below.

4. Sections showing both this and a more recent till of different character.—The Montauk type of till, while not certainly distinguishable from the Wisconsin on the basis of its lithologic characteristics, is generally of a different character. It is in most places hard and tough, contains a larger proportion of clay, and is not so loose and gravelly as the Wisconsin type. Plate 57, figure 2, illustrates the general nature of Montauk till, and figure 1 is a sample view of the Wisconsin type of till.

One of the best sections showing both types of till in contact is at Great Boars head, New Hampshire. This is a wave-cut section 15 to 20 feet in height, and is well exposed for a length of several hundred feet. The upper 5 to 10 feet is a confused unstratified deposit of till consisting of a mass of boulders 1 to 5 feet in diameter, mixed with some sand. Underlying the deposit and separated from it by a sharp line of demarkation is a very hard, clayey till, oxidized to a depth of about 2 to 5 feet, and containing many boulders as much as 2 feet in diameter. The lower till is believed to be of Montauk age and the upper till is Wisconsin.

COARSE GRAVELS

General description.—Numerous exposures of gravel deposits overlying till are known throughout New England. Many of the gravels are undoubtedly Wisconsin, but in many places there are extensive gravel deposits which appear to be of pre-Wisconsin age. These are best exposed in the valleys of Kennebec and Penobscot rivers, in Maine. They consist of unstratified or semi-stratified deposits of coarse gravels composed of fresh pebbles of all sizes and in many sections containing much sand. The sections noted occur along the main valleys and range in thickness up to 100 feet. Their upper surfaces are very irregular and they are

* W. O. Crosby: Composition of the till or boulder-clay. Proc. Boston Soc. Nat Hist., vol. xxv, 1892, pp. 118, etc.

FIGURE 1.—SECTION OF TILL (WISCONSIN TYPE) NEAR HAVERHILL, MASSACHUSETTS
Showing stratum of underlying sand

FIGURE 2.—SECTION OF TILL (MONTAUK TYPE) IN REAR OF CAR BARN ON BROADWAY, EVERETT, MASSACHUSETTS
Showing stiffness of deposit and abundance of large boulders. The upper, darker portion is mostly soil, but may consist in part of Wisconsin till

SECTIONS OF TILL, MASSACHUSETTS

overlain unconformably by marine clay. The following is a sample section exposed in the western part of Waterville, Maine:

Section of Sands and Gravels at Waterville, Maine

Material	Feet
5. Unstratified and semi-stratified clayey gravel (Wisconsin till ?)	2 to 6
4. Stratified clay	4 to 6
3. Stratified sand	2 to 5
(Unconformity.)	
2. Poorly stratified gravel	20
1. Fine brown sand	5 +
	40 +

The following section is exposed near the bank of Penobscot river, in Brewer, opposite Bangor:

Section at Brewer, Maine

Material	Feet
2. Till, containing many boulders up to 2 feet in diameter	4 to 7
1. Horizontally stratified sand and gravel	35

Relations and correlations.—The gravels are also well exposed at Portland and at Augusta, and probably at many places where they have not been recognized. They have not been seen anywhere to rest on till, but there is no reason for doubting that they are more recent than one or more till deposits. They are commonly overlain by clay, as at Augusta and Portland, and numerous borings and wells at Boston, Cambridge, Lynn, and in the Merrimac valley obtain water in gravel after penetrating clay. At Augusta and elsewhere the gravels can be seen to be overlain by Wisconsin till. The gravels have been greatly contorted in places, and the contortion can not be explained except by the theory of an overriding ice-sheet (see page 528). In age these gravels are believed to date from the beginning of the "Second Interglacial epoch" of Woodworth* in southern New England, and perhaps to correspond with the retreatal deposits of the Illinoisan in the middle West.

Distinction from Wisconsin gravels.—In most localities these gravels can not be distinguished readily from Wisconsin. In some sections, however, the evidence that they are of pre-Wisconsin age is very striking. This evidence is of threefold nature, as follows:

1. Probable erosion before deposition of overlying (pre-Wisconsin) clay.
2. Occurrence of till overlying the gravels.
3. Erosion and folding of gravels by overriding ice.

1. Erosion before deposition of overlying clay.—Evidence pointing to

* Seventeenth Ann. Rept. U. S. Geological Survey, 1896, pp. 975-988.

a time interval between the deposition of the gravels and that of the overlying clay is found partly in an apparent unconformity at the top of the gravels. In the Kennebec valley they rise in places as high as 150 feet above tide. In neighboring sections they are absent. The marine clay, which is the next succeeding deposit, in places, as at Gardiner, Augusta, Waterville, and vicinity, rests on top of the higher remnants of gravel, and elsewhere it fills gullies down nearly to sealevel. The objection might be raised that we have no evidence against the gravels having been deposited "like kames with uneven surface and sporadic distribution." While the extent of present knowledge in specific localities is not sufficient to prove positively that such is not the case, the general distribution of the gravels with rather uniform upper level renders the kame hypothesis rather weak. Even if true, it would not materially affect the general proposition of a time interval, as the change of conditions from those necessary for kame formation and those favorable to deposition of widespread well-stratified fossiliferous marine clays necessitate a more than local ice-retreat.

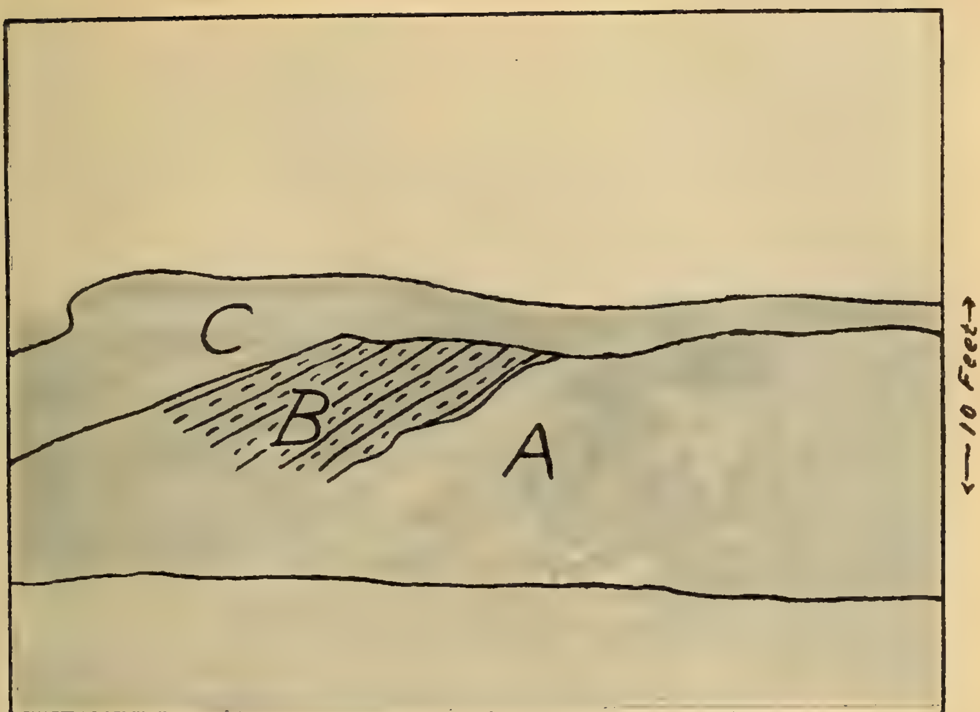
2. Occurrence of till overlying the gravels.—One of the best exposures of till overlying stratified sand, clay, and gravel is to be seen on the southern edge of the village of Augusta, Maine. There are a number of good exposures in gravel pits at this place, which appear to throw light on the succession of events after the deposition of the gravel. Plate 58, figure 1, shows a section where coarse semi-stratified gravel of unknown thickness is overlain by 15 feet of clay and fine sand, folded at a high angle. These deposits are cut off squarely at the top, as if planed off by ice, and are overlain unconformably by 2 to 6 feet of till.

3. Erosion and folding of gravels by overriding ice.—This erosion was accompanied by severe folding, as illustrated in a pit a few hundred feet from the last (see plate 58, figure 2). The illustrations show that the folding took place after deposition of the clay (B), and that at the same or a subsequent date there was erosion with the deposition of till (Wisconsin). Other sections in the vicinity show the clay (B) increasing to as much as 30 feet in thickness and forming part of the main marine clay deposit of the valley.* The lower 5 feet of the clay is, as a rule, very sandy, as in figure 1. The shoving illustrated in this plate took place from the north, at the right hand end of the section.

FOSSILIFEROUS MARINE CLAYS ("LEDA CLAY")

Use of term "Leda clay."—The name "Leda clay" was applied in 1857 by Dawson to the fossiliferous marine clays at Montreal,† from *Leda*

* A. S. Packard: Mem. Boston Soc. Nat. Hist., 1865, p. 243.
† J. W. Dawson: On the newer Pliocene and the post-Pliocene of the vicinity of Montreal. Canadian Naturalist, 1857.


C
B
A
←10 Feet→

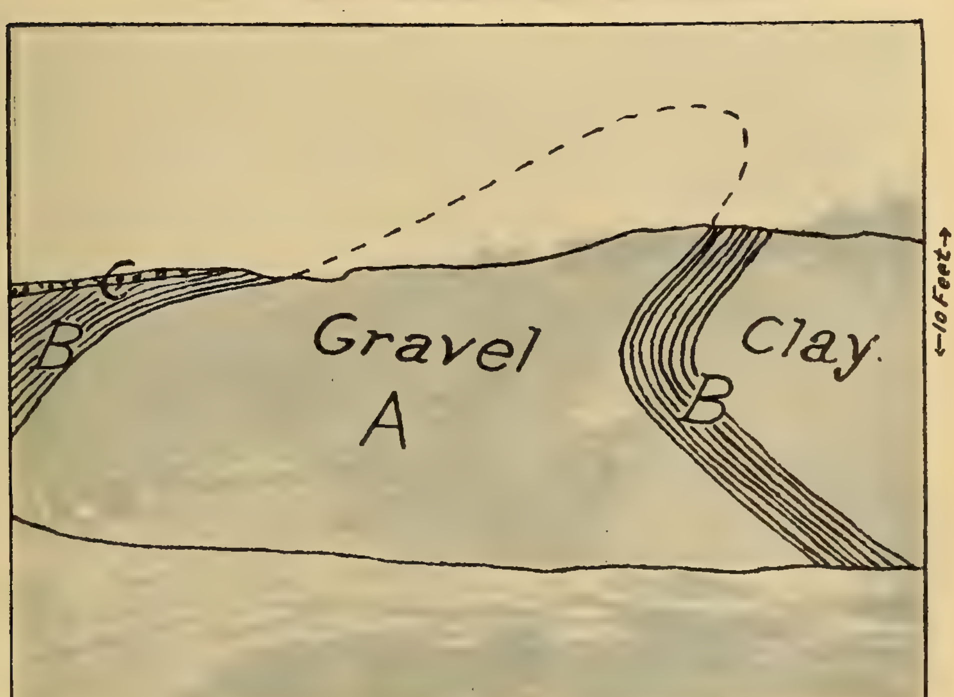

C
B
Gravel
A
Clay.
B
←10 Feet→

FIGURE 1.—SECTION SHOWING WISCONSIN TILL UNCONFORMABLY OVERLYING FOLDED STRATIFIED DEPOSITS, AUGUSTA, MAINE

A, gravel; B, marine clay and fine sand; C, Wisconsin till

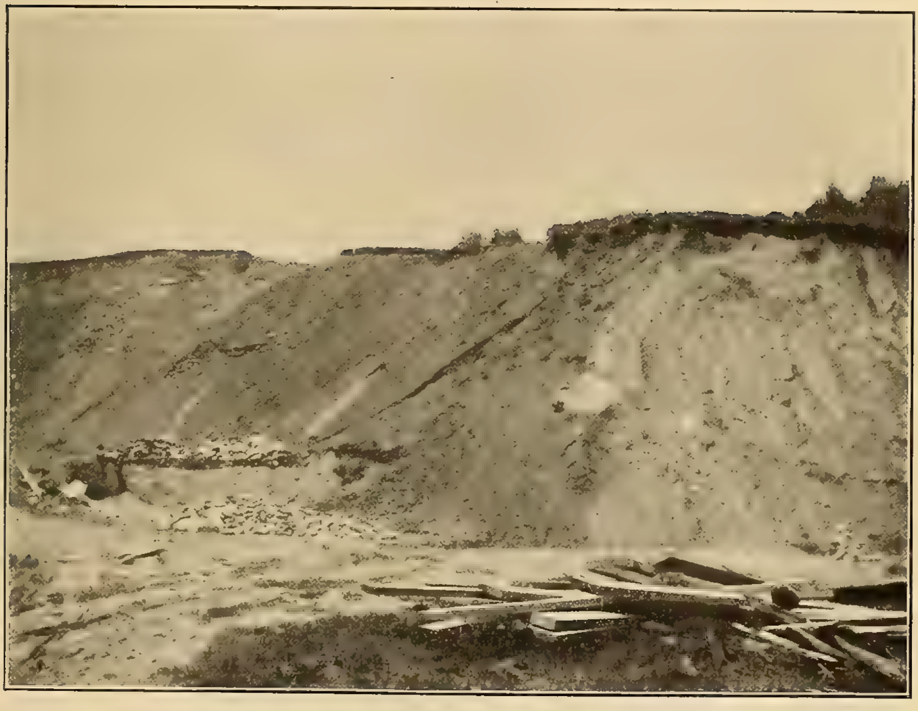


FIGURE 2.—SECTION SHOWING FOLDING AND EROSION OF MARINE CLAY BY OVER-RIDING WISCONSIN ICE-SHEET, AUGUSTA, MAINE

A, B, and C are same as in figure 1

SECTIONS OF WISCONSIN TILL AND MARINE CLAY, MAINE

truncata, which was found abundantly in the formation. The overlying sands were called "Saxicava sands" for the reason that they contain *Saxicava rugosa.* Since that time the marine clays of the Saint Lawrence valley and the New England coast have been studied by various geologists, and the name "Leda clay" has been generally applied to any marine clay in this region. It now seems clear, however, that the clays classed under that name are not all of the same age. For this reason the name "Leda clay" will be avoided, so far as possible, in this paper.

General description.—Below the limit of surface oxidation the marine clays are commonly blue drab to gray in color, finely laminated and evenly bedded, often containing thin laminæ of sand. There is considerable diversity of character; sometimes the clays grade horizontally into fine sand, and in places they contain layers of "marsh mud" which has a strong odor. Polished boulders are frequently found, and in places, as in the Cambridge, Massachusetts, brick-yards, they are well striated. In a number of localities they are abundantly scattered through the deposit, indicating the existence of icebergs. The broad extent of the deposits containing boulders on the New England coast, in all the large valleys, and in the Saint Lawrence valley indicate, however, that the glaciers from which the ice was derived may have been several hundred miles distant. It is possible that at that time the highlands in the interior of New-England and of the province of Quebec may have been ice-covered and the coasts and the Saint Lawrence valley may have been free from ice. Packard states that the greater abundance of arctic fossils in the lower part of the clays and of forms characteristic of a milder climate in the upper part indicate that the climate became milder during the close of the clay deposition; hence it would appear fairly certain that the main areas of clay containing marine fossils must have been deposited during a retreat of the ice to a long distance. In thickness the clay is irregular, ranging in Massachusetts, New Hampshire, and in parts of the Kennebec valley in Maine up to over 100 feet, but it is commonly less than 50 feet.

Distribution.—The "Leda clays" are found far and wide throughout the Saint Lawrence valley and on the coast of Maine, New Hampshire, and in Massachusetts as far south as Boston.

Clays which do not carry fossils, but which belong in this class, are extensively developed in Cambridge, Medford, Everett, Revere, and Chelsea, near Boston, and are found at Lynn, Salem, Saugus, Newburyport, Ipswich, Amesbury, and Haverhill, in Massachusetts. At Lynn and Danvers fossils have been found in them. In New Hampshire they are finely developed at Exeter, Epping, Portsmouth, Rollinsford, and Dover.

In Maine they extend along the coast from Kittery to Eastport, forming many low plains near the sea and extending up most of the river valleys. In York county they extend 15 miles or more from the coast. In the valley of Presumpscot river they are found nearly to Sebago lake; in the Androscoggin valley to beyond Lewiston and Mechanic Falls. In the Kennebec valley they are found to contain marine fossils at Brunswick, Bowdoinham, Gardiner, Augusta, Vassalboro, Waterville, and Skowhegan. Farther north similar clays occur at higher elevations as far as Solon, and they are found in the valley of Sandy river at Farmington; but the clays above Skowhegan may possibly not be marine, as fossils have not been reported in them. The marine clays are abundant along Sheepscot river, in Lincoln county, and are widely distributed in the vicinity of Rockland, in Knox county. They extend up Penobscot river to beyond Oldtown. They are found in small patches on many of the islands in Casco, Penobscot, and Bluehill bays, and are well exposed on Mount Desert island and on the shores of Bluehill bay. In Washington county they form plains of moderate extent at many places near the coast, and in places extend for miles inland along the valleys. They are widely distributed in New Brunswick.

Fossils.—The "Leda clays" have been studied by many writers, among whom are J. W. Dawson, Jackson, C. H. Hitchcock, and Packard.* The latter writer gave complete lists of fossils from the various New England localities and postulated certain theories regarding the climatic and geologic conditions at the time the clays were formed. Many other writers have given names of species found in various localities, but have not made any extensive investigations on the subject.

As differences in Pleistocene faunas are due chiefly to slight differences in climate, it is not supposed that correlations between the several clay

* J. W. Dawson: On the newer Pliocene and post-Pliocene of the vicinity of Montreal. Canadian Naturalist. 1857.

Additional notes on the post-Pliocene deposits of the Saint Lawrence valley. Canadian Naturalist, 1859.

On the climate of Canada in the post-Pliocene period. Canadian Naturalist, 1860.

On post-Tertiary fossils from Labrador. Canadian Naturalist, 1860.

On the geology of Murray bay (part 3, post-Pliocene deposits). Canadian Naturalist, 1861.

On the post-Pliocene deposits of Riviere du Loup and Tadoussac. Canadian Naturalist, 1865.

The post-Pliocene geology of Canada. Canadian Naturalist, second series, vol. vi, 1872, pp. 19-42, 166-187, 241-259.

C. T. Jackson: First, second, and third reports on the geology of the state of Maine, 1837-1839.

C. H. Hitchcock: Notes on the geology of Maine. Proc. Portland Soc. Nat. Hist., vol. 1, part 1, 1862, pp. 72-85, and numerous other references.

A. S. Packard, Jr.: Observations on the glacial phenomena of Labrador and Maine. Mem. Boston Soc. Nat. Hist., vol. 1, 1865, pp. 210-303.

deposits in New England can be made with certainty on this basis alone. Fossils are of some value, however, in checking the conclusions formed on the basis of stratigraphic evidence.

Columns 1 to 6 in the table (pages 520-523) are localities in which the clays (Gardiner) are believed to antedate the principal till deposit (page 524). The remaining columns are those containing names of fossils found in the more recent clays. It is probable that most of these latter occurrences belong to the main clay deposit, but, owing to the fact that the clays in general can not be differentiated on paleontologic or lithologic evidence, it is possible that some of them may be of post-Wisconsin age (see page 553).

Distinction between high-level and low-level clays.—A study of the marine clay deposits in the field shows at least two distinct topographic types:

First. Over wide areas the clay is characterized by a very "old-looking" topography. This type of clay is found in localities more or less protected from erosion in nearly every large valley between Boston and the New Brunswick line. It rises from 20 feet above sealevel near Boston to 70 feet in the Merrimac valley, 100 feet in New Hampshire, and about 300 feet in parts of the Kennebec valley in Maine.

Second. In many regions along the coast, in Massachusetts, New Hampshire, and Maine, there are broad, flat deposits of clay which do not rise more than 20 to 60 feet above tide. These are not remnants of elevated clays having old topography, but are generally found in localities exposed to erosion and are commonly characterized by flat surfaces. The valleys cut in them are mostly deep V-shaped valleys, which appear very recent.

For convenience of description the first type of clay will be spoken of as the "high-level" clay and the second type as the "low-level" clay. The high-level clay comprises the deposits described on pages 531-544, and the low-level clay is described on page 553.

Relations of the high-level clay.—In Massachusetts and New Hampshire even the high-level clay is at such a low elevation that its base is seldom seen, and wells frequently penetrate it to depths of over 150 feet. Numerous well records in Cambridge, Revere, Everett, Saugus, Lynn, Salem, and Newburyport, Massachusetts, and in Exeter, New Hampshire, pass out of clay at depths of 30 to 100 feet into underlying water-bearing gravels. In Maine, and especially in the valleys of the Kennebec and other rivers, the clay can be seen to rest unconformably on the gravels. In places it lies in the bottom of the valley, while in others its base rises to a height of over 150 feet. This indicates that the land may have

stood at a much higher level during the deposition of the gravels and subsided before the deposition of the clay.

Another explanation of the unconformity lies in the possibility that the gravels may represent morainal or kame deposits formed under water between the ice and the valley walls. In either case the subsequent thick deposit of clay filled all the inequalities in the bottom of the valley, resulting in the unconformity as we find it.

Correlations.—The "high-level" clays are found to rest in places unconformably on gravel; in others on tough, stony, clayey till of probably Montauk age, as at York, Maine, and at Danvers and Cambridge, Massachusetts. In a few cases the clays have been seen to rest on rock, but as a rule till or gravel intervenes.

As the clay contains fossils at numerous localities, some of them in close proximity to glaciated boulders, the material must have been deposited when the ice-front was still not over a few hundred miles distant. The facts can be accounted for by the supposition that the clays were deposited while the ice-front retreated northward across the states of Maine and New Hampshire, the boulders being transported by icebergs broken off the ice-front in the Kennebec, Androscoggin, Penobscot, and other large valleys. The presence of similar phenomena in the Saint Lawrence valley can be explained by the assumption that the ice remained on the highlands of the interior of New England and of Canada long after the Saint Lawrence valley was free and open to the ocean.

The marine clays are overlain in places conformably by a few feet of fine sand ("Saxicava sand" of Dawson) (see plate 59, figure 1). In other places they are overlain unconformably by sands. Over wide areas in southern Maine the irregularities are filled and the whole deposit obscured by broad outwash plains of sand sloping seaward. On these sand plains no till is found, but where the clay is not buried by sand it can often be seen to be covered by a heterogeneous gravelly deposit, in places, as at Exeter, New Hampshire, forming small moraines, and believed to be Wisconsin till (pages 536-537). The clay covered by this material is the "high-level clay" of pre-Wisconsin age, which was probably deposited in the Vineyard interval of Woodworth. Being subsequent to the post-Montauk gravels, which have been provisionally correlated with the Illinoisan, the clay would seem to be somewhere near Iowan in age. Although very unlike in lithologic character, it has certain aspects in relations and distribution which resemble some of the water-laid types of the Iowan loess of the West.

Evidence that this clay is not of Wisconsin age.—The evidence supporting the view that the "high-level" clays are of pre-Wisconsin age is as follows:

FIGURE 1.—HIGH-LEVEL TYPE OF MARINE CLAY, DOVER, NEW HAMPSHIRE

The clay is overlain conformably by stratified sands, which are in turn unconformably overlain by unstratified sands

FIGURE 2.—LOW LEVEL OF MARINE CLAY, ROLLINSFORD, NEW HAMPSHIRE

Viewed from a gentle till slope

TYPES OF MARINE CLAY, NEW HAMPSHIRE

1. Greater weathering and oxidation than deposits of Wisconsin age.
2. Occurrence of oxidized zones at the top of buried clay surfaces which were formed by subaerial erosion.
3. Occurrence of overlying till and morainal deposits.
4. Folding and erosion due to action of overriding ice.
5. Reworked upper portion of clays.
6. Older topography and greater elevation of these clays than of certain clays believed to be of Wisconsin age.
7. Occurrence of overlying buried soils.

1. Degree of oxidation.—Something of the relative ages of different deposits can be inferred from the relative depths of superficial oxidation or yellowing due to action of the weather. In connection with the Montauk till (page 525), it was stated that the oxidation of that material was much deeper than that of the ordinary superficial till. The oxidation of the former is 10 to 20 feet deep, while the latter, notwithstanding its looser and more pervious character, is, as a rule, not yellowed over 3 to 5 feet. This can be seen in the ordinary boulder-clay over large areas in southern Maine. The marine clays are like the Montauk till in being rather deeply oxidized, in most places being yellowed to a depth of 5 to 12 feet from the surface. The following exposures will serve as examples:

At many brick-yards in Medford, Chelsea, and Everett, Massachusetts, the upper 5 to 10 feet of the clay are buff or mottled and in places somewhat blocky, below which it is blue drab in color. In this region the upper 3 to 5 feet are in some places rather stony and appear to be in reality till composed largely of reworked clay.

At Trask's brick-yard, Danvers, 9 feet of buff gray clay have been seen to overlie the blue clay.

At a brick-yard in Lewiston, Maine, about 200 feet above tide, 12 feet of buff clay are exposed over 20 feet or more of blue clay.

At Mechanic Falls, Maine, 20 feet of clay are exposed in a brick-yard; the upper 5 feet are very yellow, while below that it is blue.

Near the village of Eliot, Maine, where 10 feet of clay can be seen to be overlain by 2 to 5 feet of sand, the upper 5 to 8 feet of clay are grayish, but the lower part is blue.

In Brewer, Maine, 30 feet of well stratified clay are exposed, and the upper 8 to 15 feet are yellowish, while the rest is blue.

In Chelsea, Maine, the upper 12 feet of the clay are buff brown, the rest being blue drab.

Some places have been seen where the yellowing extends only 2 to 3 feet from the surface. This might be supposed to favor the view, ad-

vanced by some, that the differences in depth of weathering were due to different conditions of moisture, porosity or climate in different localities. In all cases, however, the differences could be accounted for by (*a*) the peculiar situation of the deposit—that is, where it might be a part of the "low-level" or Wisconsin deposit, or (*b*) the possibility of part of the surface having been removed by erosion since the weathering took place. Oxidation of 5 to 12 feet in the clays has been noted by Crosby in his studies of the materials found in borings at Boston.

2. Oxidation of buried clay surfaces which were formed by subaerial erosion.—Evidence of an elevation and a subsidence since the deposition of the principal clay deposit is found in a series of borings made in 1905 at Vaughans bridge over Fore river at Portland. In making tests here two rows of 13 borings each were put down across the river between Portland and South Portland. The borings were sunk to bed-rock, which dips rather regularly from 45 feet below mean low water on the Portland side to 110 feet below on the South Portland side. A typical record is as follows, beginning at low-water level:

Boring for Vaughans Bridge, Portland, Maine

Material	Feet
Water	11.9
5. Soft black silt	21.4
4. Soft black sand and peat	21.0
3. Very soft blue clay, with silt	52.8
2. Coarse gravel and sand, hard	2.4
1. Rock.	
Total	109.5

Samples of these deposits were on exhibition at City Hall, and were examined by the writer. Number 5 is a brownish gray clay, rather silty and similar to much of the clay found 20 to 40 feet above tide in the vicinity of Portland. Number 4 is in some cases a nearly pure peat; in others it is made up largely of sand. It is only found in 10 out of the 26 borings, and has a thickness, where mixed with sand, of from 5 to 30 feet. Its upper surface rises to within about 30 feet of the present low-water level. Number 3 is a typical blue clay, a little lighter in color than number 5 and resembling some brick-yard clays seen in southwestern Maine. The surface of this deposit rises from —55 feet at South Portland to sealevel at Portland. The top of this clay is yellow to the depth of several feet below the overlying deposits. Number 2 is a typical stony till of the Montauk type.

The descent of the clay from sealevel to 55 feet below, with an oxidized

upper surface overlain by a horizontal deposit of peat and soil, can only be explained by erosion and subsidence since the clay was deposited. The chief question in this connection is the age of the clay. It overlies till and is therefore Quaternary. When its topography is compared with the flat and little eroded clays of the Maine coast, it must be considered somewhat older than they; and if they are of post-Wisconsin age, this clay probably corresponds with the greatly eroded "high-level" clays of Maine which are under discussion here. The borings indicate an elevation of the coast (post-Montauk) to at least 50 feet above the present sealevel at Portland, followed by erosion, which is indicated by the soil and oxidation zones to have been interglacial; then came a subsidence to at least 80 feet below sealevel, when the later clays were deposited, followed by the recent elevation, which raised the clays at least 80 feet above tide at this place.

Extensive boring at Boston has revealed similar erosion of the clays, and indication of an interglacial stage is furnished by occasional examples of oxidized deposits overlain by more recent deposits of clay, gravel, and till. A detailed study of samples from these borings has been made by Crosby,* who reports a superficial yellowing on the clay underlying the harbor silts. The clay at Boston is characterized by an unconformity similar to that at Portland. Borings along the line of the subways, the East Boston tunnel, and extensive bridge and well boring in the city and harbor show a widespread deposit of clay extending from 5 feet above tide to 200 feet below tide. The yellow, or oxidized clay, is sometimes found as much as 30 feet below low water. Regarding this feature, Crosby writes as follows:

"Oxidation makes the clay, and also the boulder-clay, harder and firmer, by cementing the clay particles by iron oxide; and this may explain the fact that the boring records often indicate 'hard clay' above, passing downward through 'stiff clay' to 'soft clay.'"

The following is selected by the present writer as a typical boring section. It is situated at the corner of Beach street and Atlantic avenue:

Section of Boring at Boston

Material	Feet
4. Filling	19
3. Hard yellow clay, sand	7
2. Hard yellow clay	5
1. Soft blue clay	28
Total	59

* A study of the geology of the Charles River estuary and the formation of Boston harbor, in "Report of the committee on the Charles River dam," Boston, 1903, pp. 345-369.

In most borings the depth of oxidation is 5 to 15 feet, but a few records have been seen in which it is over 20 feet. No two borings give exactly the same section, and to show the variations in a short distance the following is given. It is situated midway between Beach and Essex streets on Atlantic avenue.

Section of Boring at Boston

Material	Feet
7. Filling	9
6. Fine sand, mud	4
5. Hard yellow clay, little sand	5
4. Little clay, sand, coarse gravel	4
3. Hard blue clay, sand	11
2. Hard blue clay	10
1. Clay, sand, gravel, hard	8
Total	51

The great number of borings at Boston makes it possible to trace out with some degree of accuracy the courses of valleys which were deeply eroded in the clay, and subsequently buried by sand and other deposits. As stated by Crosby, the maximum depth of valleys in the blue clay is 50 feet.

"That the erosion of the clay producing all the depressions now occupied by the inner harbor was subaerial and not marine, fluvial and not tidal, and that it extended over a long time, are indicated by the superficial yellowing of the clay through the oxidizing influence of the atmosphere."

Crosby, however, believed the clay to be of Wisconsin age.

Evidence that the drumlins are older than the principal clay in the borings was found on Hanover street, where the "toe" of Copps Hill drumlin descends to —30 feet and the clay rests on top of it. Nearly everywhere the clay is underlain by a stony hard-pan believed to be Montauk, and in many places the oxidized upper surface of the clay is overlain by a hard gravelly deposit resembling Wisconsin till (pages 546-547). The deep oxidation of the clay—as deep as the deepest oxidation of the underlying till where it is exposed—and the correspondence of the clay oxidation with an unconformity which must have taken thousands of years to form, being later covered with sands, gravels, and silts, indicate the interglacial age of this clay with a strong degree of probability.

3. Occurrence of overlying till and morainal deposits.—Good sections have been seen of till overlying clay at a number of places in northeastern New England. One of the best examples is at the works of the New England Brick company, 2 miles south of Exeter, New Hampshire, where

a section over 100 yards long shows 8 feet of till resting on marine clay. The exposures can be seen in two brick-yards situated on either side of the Boston and Maine railroad. The till consists of an unconsolidated deposit of clay, gravel, and boulders, and is oxidized to a depth of 2 feet from the top. The underlying clay is normally horizontal and contains some layers of interstratified sand. Mr George C. Matson reports a fault in the sand here and states that the strata are considerably contorted. In elevation the clay rises about 100 or 120 feet above tide. Back from the clay pits the till surface rises into a moraine-like deposit. Beneath the clay another deposit of till, which appears to be Montauk, is found. The pebbles contained in it are, however, decomposed to an extent unusual in the Montauk till. Similar conditions prevail in a pit of the same company 2 miles farther north.

A condition similar to that at Exeter is found at Newburyport, Massachusetts. The clay at that place is overlain by sand and gravel, which is in turn overlain, east of the railroad, by till (see plate 60, figure 1).

Section of Drift at Newburyport, Massachusetts

Material	Feet
4. (Top) Typical stony, clayey till, containing pebbles up to 3 inches in diameter	4
3. White stratified sand, merging upward into till and downward into semi-stratified sand containing some pebbles	2
2. Below (3) is a reddish ferruginous crust one-half inch to one inch in thickness.	
1. Much folded and faulted sand containing a few pebbles	5 +
Total	11 +

The faulting in (1) indicates shoving from the north.

The occurrence of till over clay at Danvers and Lynn, Massachusetts, was first noted by Sears.* These deposits have been seen by the writer, who agrees with Sears in his conclusions. The latter was the first person to find fossils in these clays in Massachusetts. He believed that the overlying till formed the "toes" of near-by drumlins which were supposed to rest on clay. What is considered by the present writer a more probable condition is explained on page 550. At the Danvers locality 14 species of fossils were found by Sears (column 8, pages 520-523).

In 1866 Shaler described some fossiliferous clays and sands overlain by till at Gloucester, Massachusetts,† and 37 years later similar relations in a neighboring cliff section were discovered by Tarr.‡ The fossil forms found in this section are those noted in column 9 of the table.

* J. H. Sears: Geology of Essex county, Massachusetts. Salem, 1905, pp. 357-373.
† Proc. Boston Soc. Nat. Hist., vol. xi, pp. 27-30.
‡ Bull. Harvard Coll. Mus. Comp. Zool., vol. xlii, 1903, pp. 181-191.

In 1878 Hitchcock described fossiliferous clays interstratified between two tills at Portland.* The same writer has observed till overlying stratified clays and gravels at many places in New Hampshire.†

In the same work Upham ‡describes numerous exposures of till resting on stratified clay in the vicinity of lake Winnipiseogee. Upham interpreted the phenomena, however, as being due simply to the washing of material on top of the clay from melting of a neighboring glacier and not to any retreat and readvance of the ice.

Chalmers, in 1893,§ described an exposure of stratified clay underlying till at Nogrotown point, New Brunswick, giving sections and fossils (column 25, pages 520-523). One of his sections is as follows:

Section at Fern Ledges, near Saint John, New Brunswick

Material	Feet
4. Till with boulders up to 1 foot in diameter	13
3. Till with boulders up to 6 feet in diameter	25
2. Stratified, tough, dark red clay containing a few pebbles and occasionally a boulder	14
1. Till	10
Total	62

The following section is also reported from near Nogrotown point:

Section one-fourth Mile West of Nogrotown Point, New Brunswick

Material	Feet
4. Till	11
3. Stratified till	1
2. Till containing 7 species of fossils (see column 25, pages 520-523)	10
1. Stratified, dark red, tough clay with a few boulders, containing 7 species of fossils (see column 25, pages 520-523)	20
Total	42

There seems to be no particular evidence from the report whether the above described deposits are pre-Wisconsin and Wisconsin, or whether they are Gardiner and Montauk, but the former hypothesis is believed to be true.

The following are a few of the instances of till overlying clays seen by the writer:

* Geology of New Hampshire, vol. iii, pp. 279-282.
† Op. cit., p. 290.
‡ Op. cit., pp. 131-138.
§ Bull. Geol. Soc. Am., vol. 4, pp. 361-370.

FIGURE 1.—WISCONSIN TILL OVERLYING STRATIFIED SAND, NEWBURYPORT, MASS.

Showing faulting and folding by Wisconsin ice-sheet

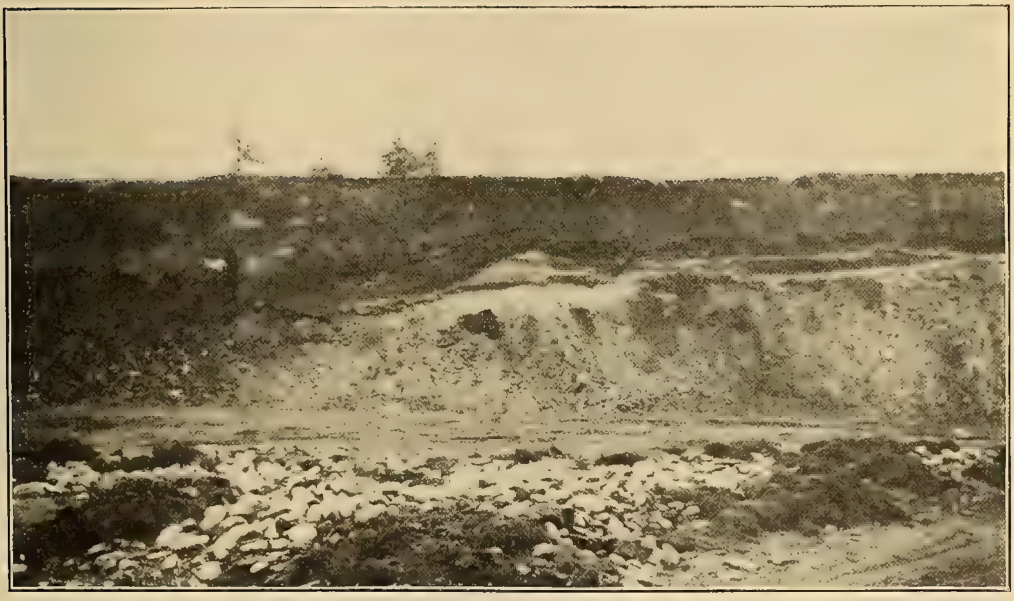


FIGURE 2.—SECTION SHOWING WISCONSIN TILL OVERLYING MARINE CLAY, DEERING, MAINE

The clay rests unconformably on stratified sand and gravel

RELATIONS OF WISCONSIN TILL, MASSACHUSETTS AND MAINE

Along the Washington County railroad between Cherryfield and Calais, Maine, a number of good railroad cuts show till resting on clay.

In a road section at Ottar cliff, Mount Desert island, are 4 to 6 feet of a moraine-like deposit of unassorted gravels containing boulders up to 2½ feet in diameter, underlain by hard tough clay containing no pebbles. This clay is somewhat yellowed through surface oxidation.

At Kittery, York, and other places in Maine, and at Revere, Danvers, and Newburyport, Massachusetts, large boulders have been seen to rest on clay. At York an exposure of till resting on clay was seen.

4. Folding and erosion due to action of overriding ice.—In many places in this part of New England clays, sands, and gravels have been seen which must have been originally horizontal, but which are now highly folded. The principal examples are as follows:

A section is given by Marbut and Woodworth * showing contorted clays on the west side of Fresh pond, in Cambridge, Massachusetts. Folds and eroded upper surfaces of the clays, which are attributed by those writers to overthrusting by ice, are also exposed in the clay pits at Cambridge.

Two miles north of Haverhill, Massachusetts, on the east side of Little river, a brick clay similar to that in the neighboring valley bottom is folded up over gravel deposits 20 feet or more in height.

At Augusta, Maine, a gravel pit several hundred feet long shows 35 feet of gravel overlain by 8 feet of stratified sand, and above that lie 20 feet of clay. As shown in plate 58, figure 2, the clay in the center of the pit is nearly horizontal. At the northern end of the section, however, it rises in an overturned fold and is truncated by the surface of the hill. Over a distance of 100 feet at the surface the clay is missing, but about the center of the exposure it comes in again and descends with a dip of 15 to 45 degrees to the base of the section at its south end. The supposed former extent of the clay is shown by the dotted line.

About 200 feet west of this main gravel pit is a smaller excavation in which the same beds are seen. They differ from those in the first section in the respect that the clay in the second section contains many sandy layers, and is probably a somewhat lower part of the clay formation. The gravel underlying the sandy clay here is inclined 30 to 45 degrees from the horizontal. The beds are truncated at the top and are overlain by a very clayey and stony till which ranges in thickness from 2 to 6 feet (plate 58, figure 1). In both these sections the strata of sand and clay are inclined toward the south, but the fold is high and overturned toward the north, indicating that the shoving which produced the folding took place from the latter direction. It seems a fair supposition that this

* Seventeenth Ann. Rept. U. S. Geological Survey, part 1, p. 990.

shoving was produced by the Wisconsin ice-sheet. That the Augusta clay is marine is proved by shells found in it by C. T. Jackson* (column 19, pages 520-523). To the argument that the folding may have been produced by a merely local readvance, the answer can be made (*a*) that the clay in the Augusta sections represents the marine clay which was deposited when the valley ice-front stood at least as far north as Waterville, and (*b*) that a local ice-advance after the deposition of a considerable thickness of marine clay would presumably not have exerted so great a power of folding and erosion as took place at Augusta. The general upper level of the clay at Augusta is 200 to 220 feet above tide. Along the electric car line 1 to 2 miles west of that city, however, is a rather flat-topped hill, where clay similar to that in the valley rises above 300 feet. As this exposure was not examined on foot, no definite statement can be made regarding it, but either (*a*) this must be a still older clay than the ordinary "high-level" clay, or (*b*) it must have reached its greater altitude through ice-shoving.

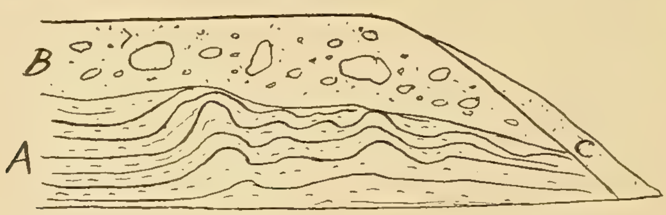


FIGURE 5.—*Section of Till (Wisconsin) resting on stratified Sand and Clay, near Haverhill, Massachusetts.*

A, fine sand, interstratified with thin layers of clay, worked in a brick-yard one-half mile east; B, clayey, sandy till, containing boulders up to two feet in diameter; C, ashes, artificial filling.

About a mile east of Haverhill, Massachusetts, on the road to Groveland, is an exposure, part of which is illustrated in plate 57, figure 1. The upper bouldery and gravelly till rests on stratified sand and clay, and a few feet distant, where the material is more clayey, it is much contorted, as if by overriding ice (see figure 5).

On the western slope of Munjoy hill, Portland, back of the car-barn, is a section which shows over 10 feet of Montauk till overlain by 3 to 5 feet of stratified and crumpled sand and clay, which are in turn overlain by 12 to 20 feet of gravel (see figure 6). It is possible that the upper 3 feet of the latter, which is strewn with large boulders, may represent Wisconsin till.

A mild type of fold in clay might be produced by the melting away of buried blocks of ice. It is difficult to imagine how an overturned fold

* Third annual report on the geology of the state of Maine, 1839, p. 35.

like that described on page 539 could be so produced, however. In several cases the occurrence of folds in which the inclination of the strata is toward the south seem to indicate a lateral pressure from the north. If lateral pressure was the cause, it can hardly have been due to anything but ice.

The general assumption in the past has been that such instances were due to local readvances of the ice. If, however, the clay at Haverhill, Augusta, Portland, and elsewhere is of the same age as that in Portland and Boston harbors, as its relations with the underlying clay and overlying gravels render probable, the evidence afforded by the subaerial erosion and oxidation of the clay surface must be taken into account as indicat-

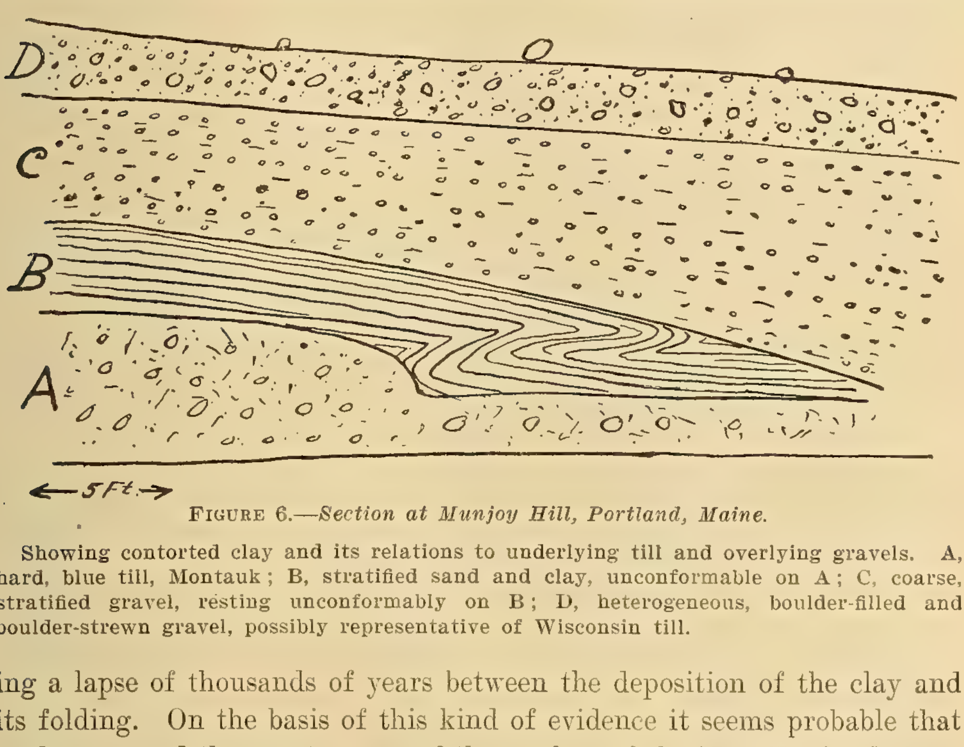


FIGURE 6.—*Section at Munjoy Hill, Portland, Maine.*

Showing contorted clay and its relations to underlying till and overlying gravels. A, hard, blue till, Montauk; B, stratified sand and clay, unconformable on A; C, coarse, stratified gravel, resting unconformably on B; D, heterogeneous, boulder-filled and boulder-strewn gravel, possibly representative of Wisconsin till.

ing a lapse of thousands of years between the deposition of the clay and its folding. On the basis of this kind of evidence it seems probable that ice has covered the greater part of the surface of the New England clays. The absence of folding and of deposits of till over considerable areas is not evidence to the contrary, for in Alaska, where living glaciers are seen, they have been observed by F. E. Wright and others to be at present retreating in places over clayey deposits with almost no deposition of till and no perceptible erosion or folding. Absence of erosion may perhaps be due to the presence of water above the deposits during the ice-advance.

5. Reworked upper part of some clays.—In most of the clay pits which have been examined the upper few feet of clay is different in character from the lower part. The upper 5 to 8 feet is commonly unstratified,

contains more abundant boulders than the underlying clay, and, so far as known, is destitute of fossils. The presence of boulders in this part of the clay more abundantly than in the lower part indicates that the upper part of the clay has been reworked by the ice; in other words, it is in reality till.

A good example of this superficial stratum is found in Edmester's brick-yard in Revere, Massachusetts, where the section is as follows:

Section in Clay Pit at Revere, Massachusetts

Material	Feet
3. Peat	4
2. Buff, very stony till, with boulders up to one foot in diameter	2
1. Buff, blocky clay, with a few pebbles	6
Total	12

Similar exposures were seen in other pits near Revere and in Lynn, Saugus, and Danvers, Massachusetts.

An important question which must be answered in every observation of till over clay is whether the upper material is positively "till." We know that deposits of gravel, both angular and rounded, occur in places as beach deposits overlying clay, and in such cases it is frequently difficult to distinguish their true mode of origin. Certain till-like deposits seen on Mount Desert island and in Washington county, Maine, are of this type. The exposures described at Newburyport, Exeter, and many other places, however, are in situations where the deposits could not have been formed through wave action. Both of these deposits are too extensive to be iceberg-dropped. It is true, as has been said, that the latest till (Wisconsin) contains rounded pebbles much more abundantly than striated ones, but such an occurrence is to be expected on account of the peculiar nature and relations of the Wisconsin ice-sheet (page 545). Moreover, while striated boulders are not abundant in Wisconsin till, they do occur, and for this reason Wisconsin till on the lee side of rock hills can frequently not be distinguished in lithological characteristics from Montauk till. This is illustrated in numerous exposures in the vicinity of Boston, where the only method of recognizing the till as Wisconsin is by its slighter amount of oxidation than the Montauk. In this region the exceptional clayey nature of the Wisconsin till is due to the movement of the ice over broad clay plains and Montauk till deposits farther north.

6. Older topography and greater elevation of some clays than of certain clays believed to be of Wisconsin age.—Some of the best evidence of the pre-Wisconsin age of the high-level marine clay is derived from its dif-

ferences in elevation and topography from the low-level clays. Along the coast, the latter, at Lynn and Salem in Massachusetts, Portsmouth and Dover in New Hampshire, and at Eliot, York, Saco, Portland, Brunswick, Rockland, Bluehill, Milbridge, Addison, and Lubec in Maine, consist of broad clay plains of elevations ranging from 20 to 80 feet above tide. These plains are commonly but slightly eroded and their upper surfaces have a very "recent looking" topography. Sometimes the clay is overlain by stratified sand, but no till and but very little gravel is found on it. These plains are believed to be of late Wisconsin age.

One of the striking features noticeable regarding the clays in general, however, is the great range in their maximum elevation at different localities. Along the greater part of the Maine coast and in the Kennebec, Penobscot, and other large valleys they present striking differences in elevation. At Boston this level is but a few feet above tide; at Saugus and Danvers, Massachusetts, it is 60 feet; at Ipswich not over 60 feet; at Amesbury and Haverhill, in the Merrimac valley, 70 to 80 feet; at Exeter, New Hampshire, 100 feet; at North Berwick, Maine, 120 feet; at Westbrook, 150 feet; at North Yarmouth and Gray, 180 feet; at Lisbon and Lewiston, in the Androscoggin valley, 200 feet; at Gardiner, in the Kennebec valley, 200 feet. Thus, from Boston to the Kennebec, there is a fairly uniform rise toward the northeast.

In the Kennebec valley the clays can be traced, with short breaks, from less than 100 feet above tide at Bowdoinham to 200 feet at Gardiner, 220 feet south of Augusta, 320 feet west of Augusta, 200 feet at Vassalboro, and 180 feet at Waterville. As far up the valley as Skowhegan marine fossils were found by Jackson and Packard. Beyond there the clays occur up to 200 feet at Norridgewock, 300 feet at Madison, and 380 feet north of Solon; but these may be in part of fluvial or glacio-fluvial origin. The apparent rise inland was at first thought to be significant and to corroborate a recent differential elevation of the interior relative to the coastal regions, a theory which was first postulated by De Geer in 1892* and which was indicated by the 500-foot elevations of the "Leda clay" in the Saint Lawrence valley.

Abundant observations, however, showed that the highest elevations occur most abundantly in regions more or less protected from erosion, and nevertheless are more eroded than the exposed clays along the coast and the lower river valleys. Supplementary to this was the discovery, in a number of spots protected from erosion on some of the islands of the Maine coast, of patches of marine clay above 200 feet. On North Haven

* Baron Girard De Geer: On Pleistocene changes of level in eastern North America. Proc. Boston Soc. Nat. Hist., vol. xxv, pp. 454-477.

marine fossils were reported by Packard up to 217 feet above tide. Similar exposures, although unfossiliferous, were found by the writer on Mount Desert island up to 150 feet above tide, and at less elevations on the islands of Casco and Penobscot bays. Sometimes a broad, little eroded deposit of low-level clay is found near a local deposit of high-level clay, as at Rockland, Mount Desert island, Bucksport, and at several places near Portland. Such instances point to the conclusion that the high level clays were deposited thousands of years before the deposition of the low-level clays of the coast.

An interesting locality is in the western part of Augusta, where clay is found up to 320 feet on a hill standing out from the sides of the valley. Other deposits of clay in the vicinity do not rise above 220 to 250 feet above the sea. It is believed this deposit owes its higher elevation to the shoving action of ice.

7. Occurrence of overlying buried soils.—In 1872 Dawson described an occurrence of peat underlying till in Cape Breton,* and this was referred to by Hitchcock in 1878 and 1888.†

No similar exposures have been observed in New England, and it seems probable that most soils were removed by the severe glaciations to which the region was subjected. At Salisbury Beach a "quagmire" is reported beneath clay 50 feet below the surface in well records, but its exact nature is not known. At Portland a series of well records and samples has been seen where the submarine clay is overlain directly by a bed of peaty matter rising to about 30 feet below low-water mark. This bed is described on page 534. As the peat fills the channels in the clay, which has been eroded to a depth of 55 feet since the deposition of the latter, there seems good evidence of an extended elevation and subsidence of the land preceding the present epoch.

WISCONSIN TILL

General description.—The great mass of the till in New England is the Montauk boulder-clay, described on pages 524-526. Over most of the region there is another type of till, overlying the Montauk and consisting, as a rule, of a heterogeneous deposit of gravel, boulders, and sometimes a little clay. The common appearance of these deposits is illustrated in plate 57, figure 1, where a bed of stratified sand can be seen underlying the till. As a rule, this type of till contains much less clay than does the Montauk type. It is known to form the surface nearly everywhere

* Canadian Naturalist, second series, vol. vi, p. 178.

† Supplement to the second edition of Acadian Geology, pp. 27-28. Report of the subcommittee on the Quaternary and Recent. American Geologist, vol. ii, pp. 300-306.

except on top of the Wisconsin sand, gravel, and clay plains. In thickness it ranges from a few inches to 40 feet, but is commonly only 3 to 6 feet. This surficial type of till is believed to be Wisconsin in age.

Evidence of Wisconsin age.—The evidence that this till is of Wisconsin age is fivefold, namely:

1. It is the uppermost till in the region.
2. It is different in character from underlying tills.
3. It is underlain in many places by stratified deposits of sand, gravel, and clay.
4. As a rule, it is but slightly oxidized at the surface.
5. In many exposures there are veneers of this till over Montauk type of till.

1. Uppermost till in the region.—This statement explains itself, and has heretofore led to the belief that all the New England till was Wisconsin.

2. Difference in character from lower tills.—The upper till in most places is very different in character from the Montauk type. As stated above, it is loose and more gravelly and its boulders are seldom well striated. Its character is to a greater extent dependent on the character of the underlying drift formations. For example, over a large part of the town of Standish, south of Sebago lake, Maine, the surface till is very sandy and gravelly, appearing more like what has been generally classed as morainal material. In other places, as over some of the high-level clay plains in southern Maine, the upper few feet consist of an unstratified and frequently rather sandy type of clay containing more numerous boulders than does the lower part. This is believed to be clay which has been reworked by the overriding ice and is in reality till. Generally no distinct line of demarkation from the underlying clay can be seen, but where the upper zone is readily recognizable as till it is in most places very clayey. Few boulders are seen over the broad expanses of clay plains, but a significant fact is that in the lee of some rock hills boulders are numerous. Moreover, by far the greater proportion of material in all till is of local origin.

These facts can be explained on the assumption that the Montauk sheet, like the Wisconsin ice-sheet, left in its retreat glacial lakes in which sand plains, moraines, and other deposits were formed. When, after the elapse of some thousands of years, the Wisconsin ice-sheet extended southward over these retreatal deposits it must have incorporated large amounts of the interglacial sands and water-worn gravels.

A characteristic of till, in New England and elsewhere, is its dependence in composition to a certain extent on the composition of the under-

lying formations. Where the Wisconsin ice moved over the great sand and gravel plains of Long island its deposits consisted chiefly of gravel. In New York, Pennsylvania, and New England the boundary of a sandstone outcrop can often be located very closely by the abrupt appearance of a large proportion of sandstone boulders in the drift. On mount Katahdin, Maine, a mountain of solid granite, the most careful search fails to find a trace of foreign drift; nevertheless the topography of the mountain shows that the ice has passed nearly, if not entirely, over it. The movement of the ice was everywhere so slow that it seems to have incorporated boulders of the underlying rock and often deposited them within a few hundred feet of their parent ledges. The greater proportion of gravel and of rounded material in the Wisconsin ice is thus explained by the abundance of gravel in the pre-Wisconsin retreatal deposits. This, like the boulders, was scooped up and sometimes deposited within a short distance of its original resting place. In the same way, ice in passing over a clay plain can take up nothing but clay, and when it retreats the clay, with its incorporated gravel and boulders, is deposited largely within the boundaries of the original deposit. In a vertical cut the reworked portion of pre-Wisconsin clay is generally distinctly visible in the form of a non-stratified and non-fossiliferous upper portion, 5 to 8 feet in thickness, which contains more abundant boulders and is somewhat more sandy than the stratified clay below.

As the Montauk till was very thick in places, its retreatal deposits must have been of great bulk. We should naturally expect to find the Wisconsin till composed largely of apparently unglaciated and little glaciated material, as is actually the case. In such localities as on the south side of Sebago lake, from which the ice must have scooped up large quantities of gravel, we should expect to find an extremely gravelly type of till, such as is actually found there.

3. Occurrence of underlying stratified deposits.—The classic paper on till underlying stratified deposits in this region is the report by Marbut and Woodworth on the clays about Boston.* A few additional cases, in Revere, Chelsea, and Everett, were described in 1902 by Brown.† In many places throughout northeastern New England similar exposures have been seen which show stratified deposits underlying till of Wisconsin type. Examples of clays having these relations are given on pages 536-539. A few instances of sands and gravels underlying the Wisconsin till are as follows:

In a small roadside excavation west of lake Auburn, Maine, a deposit of very stony till was seen resting on stratified sand.

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* Seventeenth Ann. Rept. U. S. Geological Survey, part 1, pp. 989-1004.

† R. M. Brown: Am. Jour. Sci., fourth series, vol. xiv, pp. 445-450.

In a road-cut 1½ miles east of Gorham, Maine, about 5 feet of bouldery till were seen resting on 2 feet of stratified sand.

Along the Wiscasset, Waterville and Farmington railroad good exposures of till over gravel were seen.

In Whitneyville, near Machias, Maine, a section shows 2 feet of stony till overlying sand. A sand plain one-half mile or more in extent at this place is covered with large boulders, giving the appearance of Wisconsin till.

In Columbia Falls, Maine, 1 to 5 feet of till containing boulders up to 3 feet in diameter rests on sand.

The following section was seen at Brewer, Maine, in a gravel pit a short distance above the bridge across the river:

Section at Brewer, Maine

Material	Feet
3. Semi-stratified clay, perhaps somewhat reworked	5
2. Till very full of boulders up to 2 feet in diameter	6
1. Horizontally stratified sand and gravel	35
Total	46

At East Orland, Maine, a well starting on a slope thickly strewn with large boulders was drilled through 87½ feet of sand, striking clay and obtaining a large amount of water.

A number of wells dug and drilled elsewhere in Maine report quicksand beneath the till which forms the surface.

In an exposure in Lynn, one-half mile north of East Saugus, Massachusetts, there is a section of partially stratified gravel upturned at an angle of 30 degrees and overlain by 2 to 6 feet of till. The gravels, although of a type that would ordinarily be called morainal, appear to have been originally horizontal, like those commonly found in sand plains and to have been contorted by overriding ice which deposited the till over them (see figure 7).

In a gravel pit one-half mile west of Danversport, Massachusetts, 2 to 8 feet of gravelly till were seen overlying 10 to 20 feet of horizontally stratified sand.

On page 515 a section at South Lawrence, Massachusetts, was described, in which 1 to 6 feet of till overlie 2 to 5 feet of stratified sand, which in turn overlies older till (figure 2).

4. Slight surface oxidation.—While the drumlin sections and other exposures of thick till of the Montauk type are normally yellowed by the effects of oxidation to a depth of 10 to 20 feet from the surface, the upper till, notwithstanding its being looser and more pervious, is never

weathered over 2 to 5 feet from the surface. Many instances have been observed, but a few will suffice as examples.

In Orange, Franklin county, Massachusetts, on the road to Warwick, there is an excellent road section showing several feet of clayey till of Montauk type, but that it is probably of Wisconsin age is shown by the fact that it is yellowed only 1 to 2 feet at the top and has a sharp line of demarkation from the unoxidized blue till below.

Along the Boston and Albany railroad just east of Palmer, Hampden county, Massachusetts, a new excavation in 1906 showed 3 to 5 feet of yellowed till, below which it is blue.

At Arlington Heights, near Boston, sections of till have been seen which were only oxidized about 2 to 3 feet.

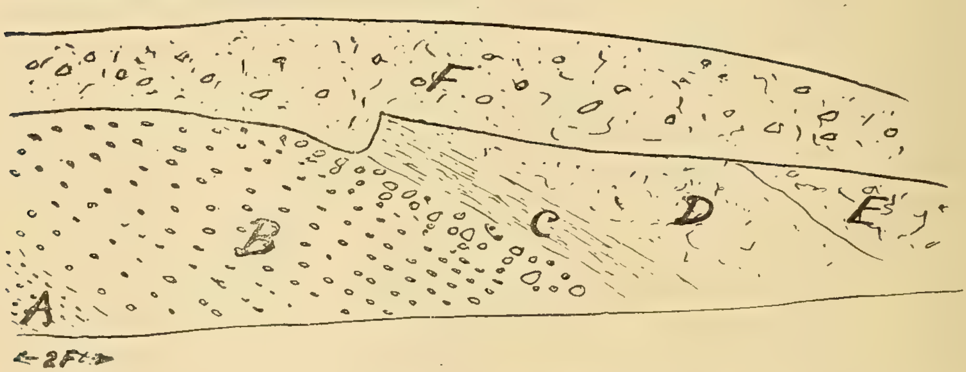

FIGURE 7.—*Section of Till overlying stratified and tilted Gravels, Lynn, Massachusetts.*

A, fine stratified gravel; B, poorly stratified gravel, with some boulders up to 6 inches in diameter; C, somewhat stratified sand and clay; D, unstratified gravel and clay, perhaps till; E, heterogeneous deposit of sand, gravel, and boulders, probably till; F, hard gravelly till, Wisconsin.

One mile northwest of Milbridge, Maine, a 10-foot section of till showed only 1 to 1½ feet of oxidation.

On Ocean drive, Mount Desert island, between Bar Harbor and Ottar cliff, are a number of 6 to 10-foot sections of till, of which 2 to 5 feet at the surface are yellowed.

Midway between the villages of Deer Isle and South Deer Isle, Maine, is a 10-foot section which is oxidized only 18 inches at the top.

On the north side of Little Chebeague island, Casco bay, is a nearly vertical 40-foot bluff of till which is oxidized only 2 to 3 feet.

Four miles south of Calais, Maine, there is a section of till which is oxidized only 3 to 5 feet, the rest of the exposure being blue in color.

5. Veneers of this till over Montauk till.—In certain localities this till is very typical and can be easily distinguished from the lower (Montauk) type of till. A good section of this kind can be seen on the north side

of Great Boars head, New Hampshire, where a cliff 20 feet high is well exposed on a small drumlin-like hill. The lower 10 to 12 feet is a hard clayey till (Montauk) containing boulders up to 2 feet in diameter. The upper surface of this till is yellowed to a depth of 2 to 5 feet. On top of this rests a looser, heterogenous deposit consisting of sand mixed with gravel and boulders up to 5 feet in diameter. The two types of deposit are separated by a sharp line of demarkation, which is somewhat irregular, but slopes westward with the surface of the hill. Part of this cliff is 40 feet high, but this part is not well exposed.

The exposures on Great Boars head and Little Boars head (figure 4) are examples of a veneering of rather gravelly till which forms the surface of most drumlins, although the coating is seldom so well marked and never so well exposed elsewhere. In many cases the two types of till can not be distinguished. In other cases the upper one is distinctly banded.

In a railroad cut at the eastern end of a drumlin one-half mile north of Revere station, on the Boston and Maine railroad, in Massachusetts, a section was seen where a superficial gravelly till rests on an underlying

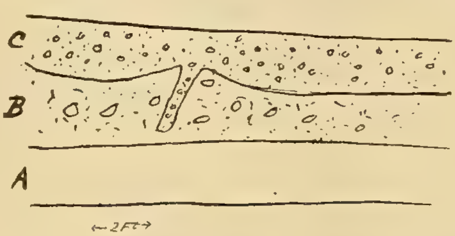

FIGURE 8.—*Section of Railroad Cut through end of Drumlin, Revere, Massachusetts.*

Showing dike of Wisconsin till in Montauk till. A, concealed; B, bouldery, clayey till; C, more gravelly and less clayey till.

clayey till, and the upper till forms a dike about 3 feet deep and several inches wide in the older till. The contact between the two tills is very sharp (see figure 8).

Other cases of veneering of more recent till over older till were seen on North ridge, Ipswich, Massachusetts, and on several drumlins south of Boston.

Drumlins are believed to antedate pre-Wisconsin clay.—The veneering of gravelly till is believed to explain certain peculiar relations of the clays to drumlins in northeastern Massachusetts. These relations are: That although the marine brick clays have been seen to rest on till of Montauk or drumlin type at many points, the clays are just as certainly overlain by till in certain places which have been observed. Marbut and Woodworth* have described many cases in Cambridge, Somerville, Saugus, Revere, and Medford where till has been seen to overlie stratified clay.

* Op. cit., pp. 995 et seq.

Those writers believed that the drumlins rested on the brick clay—an assumption which would make the clay pre-Montauk. Several clay pits in Chelsea, Everett, and Medford have been excavated directly up to the base of drumlins, and several feet of till overlie the clay there. A good example occurs in an old pit at the north end of Winter hill, Medford, where the overlying till contains boulders up to 3 feet in diameter. It can be confidently stated that the upper portion of the till rests on the clay. This till, being the latest deposit, is assumed to be Wisconsin.

Mr B. F. Smith, a prominent well-driller of Boston, repudiates the assumption that the drumlins are later than the clay, as some of his wells, sunk on the clay plain near the bases of drumlins, reach the bottom of the clay within a few feet and enter "hardpan" corresponding to the "toe" of the drumlin. He states, moreover, that not in his experience has a well drilled on a drumlin entered clay below it. In several cases, as in

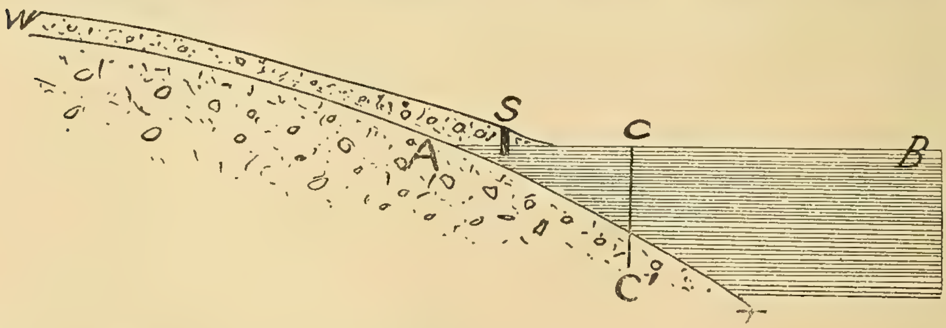

FIGURE 9.—*Sketch showing probable Relations of Clay to Drumlins near Boston, Massachusetts.*

A-B, marine clay; W-S, slope of drumlin surface; W-T, upper surface of Montauk till; S, sewer excavation near base of drumlin, passing through till into clay, according to Marbut and Woodworth; C-C′, well on clay not far from drumlin, passing through clay into till, according to Smith; W-S, Wisconsin till.

wells drilled on drumlins at Hull and Winter hill, Massachusetts, the drumlin till has been found to extend to bed-rock. If the theory of the post-Montauk age of the clay be true, Woodworth's observations can be explained as follows (figure 9):

In the sketch, A-B is the clay plain; C-C′ is a well sunk through the clay into the underlying till; S (not observed on the same drumlin, however), is a sewer excavation which penetrates till into the underlying clay; W-S is veneer of Wisconsin till which adds a few feet to the height of the drumlin W-T and extends out a short distance on the underlying clay plain.

In view of the fact that the till found in the bottom of clay pits near the base of drumlins, and which is reported in deep wells sunk in the clay,

can not be seen positively to merge with the drumlin till, there is a possibility that one of them is a third till, and that the clays extend under the drumlins in some cases. This supposition is improbable for the reason that where the till underlying the clay has been seen it can not be distinguished in character from that of the drumlins, and also because it is found in locations where it appears to slope upward and merge with the drumlin surface underlying the Wisconsin till. However this may be, a till which is in every respect like the drumlin till and apparently identical with it underlies these clays, and no evidence has been found that it is different from the drumlin till.

Another possible explanation for the discrepancy in observations is that there may be drumlins of both Montauk and Wisconsin ages, but in Massachusetts all drumlins are so similar in characteristics that none of them are believed to be Wisconsin. At a number of points on the Maine coast many miles farther northeast than the farthest known drumlin of the type found in Massachusetts and New Hampshire, a few low lenticular hills of till have been seen which may belong to a different series from those in Massachusetts and New Hampshire. The best examples of this eastern type form small islands in Penobscot and Bluehill bays.

Distinction from beach deposits.—Wisconsin till is distinguished from beach gravel by the fact that it seldom shows signs of having been assorted by water, that large boulders are found in it far from their source, that these are occasionally striated, and that the material is found in many localities far inland and in topographic situations where beaches could not be formed. In several places true ancient beach deposits have been seen, but they are all on exposed hillsides and the deposit in each case corresponds with a slight bench. The materials believed to be Wisconsin till show no such distribution or topography, but are irregularly distributed.

Distinction from iceberg-dropped material.—In cases where a material is irregularly distributed and so frequently contains large boulders as the Wisconsin till, it is pertinent to inquire whether it may not be iceberg-dropped in origin. It is true that in some places the resemblence to material that might have been dropped from icebergs is striking. In most exposures, however, only a small part of the deposit consists of boulders, and the mass forms a fairly regular layer a few feet in thickness with a rather even upper surface, while iceberg-dropped material would be expected to be more irregular in thickness and distribution. Moreover, in the case of Augusta exposures, the folding and erosion are evidence against any mode of formation except deposition from moving ice.

Striæ of diverse directions.—In a discussion of the deflection of striæ in the vicinity of Boston, Upham * shows that while the prevailing strike of the glacial striæ in Somerville and vicinity is south 20 to 30 degrees east, the drumlins in the Boston basin are all aligned with their major axes striking south 45 to 70 degrees east. A few fainter and shorter cross-striæ strike, however, south 80 degrees east, south 30 degrees west, and in other directions. Upham explains this discrepancy (page 41) by the hypothesis that the drumlins were deposited near the close of the glaciation (supposed by him to be Wisconsin), and that at that time the ice was moving more eastwardly than during the time of greatest frigidity. The fainter striæ are explained by local divergence in the direction of the ice during its later stages, when it was more dependent on the configuration of the surface.

Deflected striæ have been observed by the present writer and other persons at many points in Massachusetts and Maine, and are usually explained as Upham has explained those near Boston. The diverse strike of the drumlins, however, can be as satisfactorily explained by the probability of their having been formed at a stage previous to that of most abundant striæ. If the principal striæ are Wisconsin, the probable Montauk age of the drumlins would be corroborated, and some of the diverse striæ might be of Montauk age. A careful investigation of the directions of striæ and of the relative age of main and deflected striæ throughout the region would doubtless throw valuable light on this subject.

As the present writer has not had time to fully investigate the matter of striæ in the field, he does not feel qualified to discuss it further. It would seem important to compare the strike of drumlin axes with striæ found below drumlin till where it rests on bed-rock.

WISCONSIN RETREATAL DEPOSITS

If the theory of glacial complexity be correct, the Wisconsin retreatal deposits, as recognized in the new interpretation of phenomena, will include the ordinary kames, moraines, eskers, sand plains, and irregular deposits commonly grouped under that class, with the following important exceptions:

In many cases deposits of till have been found overlying the above mentioned types. It seems probable that only a part, and perhaps a very small part, of the retreatal deposits hitherto classed as Wisconsin belong in reality to that stage. It is believed that many of the irregularities and hitherto inexplicable phenomena in the arrangement of sand plains

* Proc. Boston Soc. Nat. Hist., vol. xxvi, 1895, pp. 33-42.

and other deposits of modified drift are due to the fact that they are actually Montauk retreatal deposits formed in Montauk glacial lakes. If this be true it may place a new interpretation on many phenomena observed in the study of sand plains and glacial lakes. As yet there are no stated criteria by which plains of the two series can be definitely distinguished, except where overlying deposits of till occur.

WISCONSIN CLAYS

As has been said, many of the flat clay plains along the coast ("low-level" clays) are certainly of Wisconsin age. As they overlie the older clays in places and are similar in character, having been formed under similar retreatal or interglacial conditions, the several clay deposits can not be distinguished with certainty. It is known that fossils occur in the pre-Wisconsin clays, but their absence in the Wisconsin clays has not been proved. Some clays are very fossiliferous, like those at Eliot, which are almost certainly Wisconsin. There seems to be no reason to expect that Wisconsin clays would be destitute of fossils, any more than clays forming in the bays at the present time. As the lapse of time between the two stages of glaciation was not sufficient to cause any radical changes in the species, there is probably no way to differentiate the post-Gardiner clays on the basis of their fossils. As they can not be differentiated by lithologic character, we must depend wholly on their stratigraphic position, amount of weathering, and topography, as explained on pages 531-544.

POST-WISCONSIN OR LATE WISCONSIN DEPOSITS

In many parts of Maine there are evidences of local valley glaciers of post-Wisconsin or late Wisconsin age. These are most pronounced in the vicinity of mount Katahdin. That several valleys on the northern slope of that mountain are shown by the position of moraines to have been occupied by local glaciers was proved by Tarr.* In the region southeast of the mountain more widely distributed evidences are found, which consist chiefly of moraines formed entirely of large granite boulders of the type found on mount Katahdin. As the strike of the glacial striæ in northeastern Maine is directly south, and as the granitic moraines are found both south and southeast of the mountain, it seems probable that the material was deposited by glaciers of post-Wisconsin or late Wisconsin age moving outward and south or southeastward from mount Katahdin

* R. S. Tarr: Glaciation of mount Katahdin, Maine. Bull. Geol. Soc. Am., vol. 11, 1900, pp. 433-448.

as a local center. The glaciers may have extended 20 miles or more from the mountain. Evidences of similar local glaciers have been discovered by Hitchcock * in the White mountains of New Hampshire and the Green mountains of Vermont, and by Rich † in the Catskill mountains of New York.

ARGUMENTS OPPOSING THE OSCILLATING ICE-FRONT THEORY

The principal objection advanced to the views outlined in this paper has been the claim that the phenomena could all be explained by the theory that the Wisconsin ice-sheet had an oscillating margin, a supposition which apparently would obviate the necessity of postulating any pre-Wisconsin glacial or interglacial epochs. While it is true that many of the features observed could be explained in that way, and the probability still remains that such may be the origin of some slight deformations and of certain instances of till over local stratified deposits, the following facts oppose the belief that an oscillating ice-front could be responsible for the great majority of phenomena observed:

1. Some of the deformations of stratified beds are on a larger scale than any likely to be produced by a merely local re-advance.

2. Many exposures of till overlying marine clay and of contorted clay are situated scores of miles south of the northern limit of the high-level clays, and the fact that the ice must have retreated sufficiently to allow deposition of these clays before the re-advance took place means a considerable time interval.

3. The common weathered zone at the top of the sand or clay and below the overlying till could be caused only by an interglacial period of some thousands of years. The deep weathering and other features of the oldest tills, described on pages 514-516 and 525-526, preclude the probability of their having been formed during Wisconsin oscillations.

4. Under the oscillation theory it is impossible to account for the prevalence of the unstratified sandy or stony upper portion of the high-level clays.

5. If the hypothesis of oscillating ice-front and post-Wisconsin age of all the clays were true, it would be necessary to explain the weathering and erosion of the high-level clays on the basis of a post-Wisconsin rise

* C. H. Hitchcock: Proc. Am. Assoc. Adv. Sci., vol. xiii, 1859, pp. 329-335; Preliminary Report on Nat. Hist. and Geol. of Maine (Sixth Ann. Rept. Maine Board of Agriculture, 1861), p. 393; Geology of New Hampshire, vol. i, 1874, pp. 539-544; Proc. Am. Assoc. Adv. Sci., vol. xxiv, part 2, 1875, pp. 92-96; Geology of New Hampshire, vol. iii, 1878, pp. 181-340; Bull. Geol. Soc. Am., vol. 7, 1896, pp. 3, 4.

† J. L. Rich: Local glaciation in the Catskill mountains. Journal of Geology, vol. xiv, 1906, pp. 113-121.

of land to a height of 60 feet or more, and a subsequent subsidence before the deposition at Boston, Portland, and elsewhere of the overlying plains of sand and gravel having every characteristic of retreatal deposits, and which themselves have been elevated and considerably eroded since their formation.

6. Glacial periods have existed in many parts of the world, and have extended in geological time from the Cambrian to the Recent; Pleistocene ice-ages, where they occur outside New England, are nearly always recognized as several in number; in New England the land surface is much more diversified and mountainous than elsewhere in the glaciated portions of this country, and consequently more favorable to the recurrence of glacial conditions. Therefore, is it not to be expected, even on a theoretical basis, that a similar sequence of events has transpired here?

Summary

To summarize, there seems to be good evidence, derived from the classes of phenomena noted on page 512 and explained on subsequent pages, that New England, like the rest of the glaciated regions of North America and Europe, has been subjected to several glacial invasions. The sequence of deposits is as outlined opposite page 512, and it is believed that they represent three glacial and two interglacial stages. The latest glacial stage that covered the whole region probably corresponds very closely with the Wisconsin glaciation of the middle West. Whether or not the Montauk glaciation occurred simultaneously with the Illinoisan and whether the pre-Montauk tills here are Kansan or pre-Kansan in age or still older is only speculation. Judging from the similarity of succession, however, there would seem to be a fair degree of probability that the Montauk glaciation occurred some time near the Illinoisan. The great extent to which weathering has gone in some of the older deposits would seem to place their date of origin more nearly with the pre-Kansan than with the Kansan.

The great difficulty in any attempted correlation between the East and the West arises through the absence of anything definite in the nature of Iowan deposits. It is true that the main pre-Wisconsin deposit of marine clay probably took place at about Iowan time, and that its topographic and structural relations are rather similar to those of the water-laid types of Iowan loess in the Mississippi valley; but in composition and origin the two deposits show no similarity. The possible presence of Iowan till in northern New England is suggested by the section at Toronto, Canada, 300 miles west of New England, where several distinct

till sheets separated by interglacial beds have been described.* The Toronto section, lying midway between the Mississippi valley and the region discussed in this paper, is one of the best of its kind, and is commonly accepted as evidence of glacial complexity as far east as New York state. It is another link in the chain of evidence that New England also was glaciated more than once.

* George Jennings: Glacial and interglacial strata of Scarboro heights. Canadian Journal, 1878, p. 388, etc.

A. P. Coleman: Glacial and interglacial deposits near Toronto. Journal of Geology, vol. iii, 1895, pp. 622-645.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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PROCEEDINGS OF THE NINETEENTH ANNUAL MEETING, HELD AT NEW YORK, N. Y., DECEMBER 27, 28, AND 29, INCLUDING PROCEEDINGS OF THE EIGHTEENTH ANNUAL MEETING OF THE CORDILLERAN SECTION, HELD AT STANFORD UNIVERSITY, CALIFORNIA, DECEMBER 28 AND 29, 1906

EDMUND OTIS HOVEY, *Secretary*

CONTENTS

Session of Thursday, December 27

The Society was called to order by Acting President William M. Davis, in the absence of President Israel C. Russell, deceased, at 4.30 o'clock p m, in the lecture hall of Schermerhorn hall, Columbia University. A brief but cordial address of welcome was delivered by President Nicholas Murray Butler, of Columbia University, to which response was made by Acting President Davis.

The report of the Council was called for, and was presented by the Secretary, Herman Leroy Fairchild, in print, as follows:

REPORT OF THE COUNCIL

To the Geological Society of America,
in Nineteenth Annual Meeting assembled:

The stated annual meeting of the Council was held at Ottawa conjointly with the meeting of the Society. It has not been found necessary to call any special meeting, but some business relating to nomination of officers and recommendation for fellowship has been done by correspondence.

The details of administration for the eighteenth year in the history of the Society are given in the following reports of the officers:

Secretary's Report

To the Council of the Geological Society of America:

Meetings.—The proceedings of the Ottawa Winter Meeting, 1905, will be recorded in the closing brochure of volume 17 of the Bulletin.

Membership.—Since the last printing of the list of Fellows four Fellows have been removed by death: W. B. Dwight, S. L. Penfield, I. C. Russell, and N. S. Shaler. The names of 16 Fellows, elected at the Ottawa meeting, have been added to the list, making the present enrollment 283, or 12 more than at the last printing. On the ballot now before the Society are the names of 14 candidates, while several nominations are awaiting action by the Council.

During recent years our membership has been increasing. In November, 1901, it was 247; in January, 1904, it was only 253. The present enrollment, with the addition of the 14 candidates on the current ballot, will make a total within three of 300. Another year will carry the list beyond 300. For several years no name has been dropped from the roll for nonpayment of dues, and only one resignation has been accepted. The increase in membership has not been due to any lowering of the standard

for admission, but to the reputation of the Society and the attraction of its fellowship for students of earth-science.

Distribution of Bulletin.—At this date 468 pages of volume 17 have been distributed, and the remaining brochures are approaching completion. The irregular distribution of the Bulletin during the past year has been as follows: Complete volumes sold to the public, 58; sold to Fellows, 14; brochures sent to supply deficiencies, 57; sold to the public, 20; sold to Fellows, 44. One copy of volume 16 has been donated and three copies bound for the use of officers and the Library. Three complete sets of the back volumes have been sold to libraries, and a partial set to a Fellow. Not many complete sets will be sold in the future, as the cost is becoming large, the greater libraries are generally supplied, and the sets belonging to deceased Fellows will be thrown on the market.

Bulletin sales.—The receipts from the sale of the Bulletin during the past year appear in the following table:

Receipts from Sale of Bulletin, December 1, 1905, to December 1, 1906

	Complete volumes.			Brochures.			Grand total.
	Public.	Fellows.	Total.	Public.	Fellows.	Total.	
Volume 1..	$10 00	$9 00	$19 00	....	....	....	$19 00
Volume 2..	10 00	4 50	14 50	....	$2 75	$2 75	17 25
Volume 3..	10 00	4 00	14 00	....	3 10	3 10	17 10
Volume 4..	10 00	7 00	17 00	$0 35	....	35	17 35
Volume 5..	10 00	4 00	14 00	45	....	45	14 45
Volume 6..	10 00	4 00	14 00	....	....	....	14 00
Volume 7..	10 00	4 00	14 00	....	....	....	14 00
Volume 8..	10 00	4 00	14 00	....	....	....	14 00
Volume 9..	10 00	4 00	14 00	....	....	....	14 00
Volume 10..	15 00	4 00	19 00	....	....	....	19 00
Volume 11..	10 00	4 50	14 50	....	....	....	14 50
Volume 12..	15 00	4 00	19 00	....	1 20	1 20	20 20
Volume 13..	15 00	4 50	19 50	4 80	4 95	9 75	29 25
Volume 14..	30 00	....	30 00	80	2 25	3 05	33 05
Volume 15..	25 00	4 50	29 50	1 15	45	1 60	31 10
Volume 16..	215 00	....	215 00	2 55	1 20	3 75	218 75
Volume 17..	200 00	....	200 00	....	....	....	200 00
Volume 18..	20 00	....	20 00	....	....	....	20 00
	$635 00	$66 00	$701 00	$10 10	$15 90	$26 00	$727 00
Index	7 00	2 25	9 25	....	....	....	9 25
	$642 00	$68 25	$710 25	$10 10	$15 90	$26 00	$736 25

Receipts for the fiscal year..........................	$736 25
Previous receipts, to December 1, 1905................	8,866 09
Total receipts to date............................	$9,602 34
Charged and uncollected...............................	100 40
Total Bulletin sales to date......................	$9,702 74

The bills to regular subscribers for volume 17 have not been sent, and the above table includes only advance payments. In another year the total receipts from the sale of the Bulletin will considerably exceed $10,000.

The publication cost of volumes 1-16 is $30,629.55, the average cost being $1,914.35. This does not include the expense of distribution. The receipts to date from the sale of the same volumes are $9,382.34, or an average of $586.40 per volume. The receipts from sale of these volumes approach one-third the cost of publication; but for the past six years the annual receipts have averaged $727.05, which is considerably more than one-third the expense of publication. The present income from sales of the Bulletin and from interest on funds, taken together, amounts to nearly 70 per cent, or more than two-thirds of the cost of the Bulletin. This would seem to be good financing for a society of small membership, depending on moderate dues for its income.

Exchanges.—Three addresses have been added to the list of exchanges—one in Mexico, one in Vienna, and one in Manila. The full list is given with the list of Library accessions, at the close of each volume of the Bulletin.

Expenses.—The following table gives the cost of administration and of Bulletin distribution during the past year:

EXPENDITURE OF SECRETARY'S OFFICE DURING THE FISCAL YEAR ENDING NOVEMBER 30, 1906

Account of Administration

Postage and telegrams	$27 90	
Expressage	6 36	
Printing (including stationery)	109 66	
Meetings (expenses of Cordilleran Section)	14 00	
Total		$157 92

Account of Bulletin

Postage	$81 40	
Expressage and freight	109 86	
Wrapping material	4 13	
Addressograph links	1 91	
Binding three copies of volume 15	3 00	
Printing	3 25	
Collection of checks	3 50	
Total		207 05
Total expenses for the year		$364 97

As this is my last report, a few words reminiscent and historical may not be amiss.

The character of the Society, the policy, and the formalities of the Secretary's office were established during the first two years, under the wise guidance of Professor Stevenson. As Editor, Doctor McGee gave the Bulletin its exemplary form, only one volume of which had been printed and sent to the Fellows when the writer was called to the Secretary's office, January, 1891. The questions of the distribution and sale of the Bulletin had yet to be considered.

The first circular advertising the Bulletin and soliciting subscriptions from libraries was dated January, 1892. From time to time efforts have been made to enlarge the subscription lists, and some advertising has been done, but with little apparent effect. The character of the publication is such that the demand can not be greatly stimulated. Where desired, the Bulletin sells itself.

Through the Editor and Secretary, the Society has been conducting a publishing business, and the Secretary has been running a sales-room by correspondence and selling the Bulletin in all parts of the world, chiefly, of course, in America.

After deliberation and correspondence, a list of "Exchanges" was made in 1891, with the purpose of placing the Bulletin at focal points of scientific influence over the world. The first list numbered 68 (see Bulletin, vol. 3, page 468). The obtaining of library material in return for the Bulletin was not an object, but was inevitable. The accumulation of exchange material led to the making of a contract in 1894 with the Case Library of Cleveland for the care of the Society's Library (see Bulletin, vol. 6, page 427), and in 1898 Professor Cushing consented to act as Librarian. (His first report is in Bulletin, vol. 10, page 422.)

The Constitution of the Society followed conventional practice in providing for several classes of members: Fellows, Correspondents, and Patrons. At one time the Council made an earnest effort to select a complimentary list of Correspondents, but after compiling and sifting many proposed names, the effort was abandoned and has never been revived. It is quite as well. One strong element of success of the Society has been its democratic spirit, and it is better that all its membership should stand on an equality. If any foreign geologist wishes to place F. G. S. A. after his name, he can do so by becoming a Fellow and paying the regular charges, as the territorial limitations to fellowship were removed in 1894.

Perhaps it is also fortunate that the Society has had no patrons, but has succeeded entirely through the character and the contributions of its fellowship (see the Treasurer's report, following).

The Secretary has preserved in a file of large scrap-books every scrap of printing, outside of the Bulletin, that the Society has ever had, along with all other material that could conveniently be pasted. These books, with the Council minutes and the Bulletin, make a perfect record of the public and the internal work of the Society. All the correspondence (with very few exceptions, of confidential papers) has been preserved. The future historiàn of the early years of what will some time be the "old" society should find nothing missing.

The writer has never missed a meeting of the Society, nor any meeting of the Council since the winter meeting in 1890. For the past sixteen years he has given a large part of his time and thought to the work of the secretaryship. It has been a labor of love, and the approval of the Fellows has been sufficient reward. To a conscientious executive officer there is a satisfaction in the control of affairs and the direction of policy, as in any work, when these are accepted and commended by those concerned. Unanimous reelection year after year has been interpreted as such approval.*

It is possible that an administration with more initiative and vigor would have produced greater results; but with our scattered membership, of strong individualities and somewhat diverse interests, it seemed safer to pursue a conservative course and let affairs move quietly and smoothly until the Society had acquired strength and prestige. The perfect unity and harmony in the Society and the Council during all the 18 years is a happy fact.

The work of the Secretary is intimately bound with that of the Treasurer and Editor and they are largely to be credited with the success of the Society. For many years of loving and laborious service the Society owes a debt to Stanley-Brown and I. C. White that only appreciation can repay. For his successor the writer bespeaks the continued sympathetic support of the fellowship, which is the best help to his success.

In surrendering office your Secretary sincerely thanks every Fellow for uniform kindness, courtesy, and support. No incident has ever occurred of character so unpleasant as to leave any remembrance. The recollection of the sixteen years of service to the Society will remain the most unalloyed and satisfying memory of a busy life.

Respectfully submitted.

H. L. Fairchild,
Secretary.

Rochester, N. Y., *December 10, 1906.*

* In fifteen elections by secret ballot the total vote has failed of unanimity only by a single vote at one election. Doctor White has always had a unanimous vote.

Treasurer's Report

To the Council of the Geological Society of America:

The Treasurer herewith submits his annual report for the year ending December 1, 1906.

On this latter date two (2) Fellows were liable to be dropped from the roll for non-payment of dues, in accordance with section 3, chapter 1, of the By-laws; six (6) were delinquent for two years, while thirty-one (31) had not yet paid for the present year.

Since December 1 8 of these have paid, leaving only 4 delinquent for 1905 and 1906 and 25 delinquent for 1906.

Five (5) Fellows, A. P. Low, A. P. Brown, R. A. Daly, S. H. Ball, and F. G. Clapp, have commuted for life by the payment of $100.00 each, thus increasing the total Life Commutations to eighty (80) at the present time.

The Permanent Publication Fund (only interest of which can be used for the current expenses of publication) was both decreased and increased during the year. This Fund amounted to $9,300.00 at the date of the last statement, of which $300.00, representing three (3) bonds of the Tunnelton, Kingwood and Fairchance railroad, matured during the year and were redeemed under date of July 28, 1906, at par and accrued interest. To offset this reduction of invested funds, 10 more shares in the Ontario Apartment House Company of Washington, D. C., were purchased by myself and Mr Emmons, the majority of the Committee on Investments, under date of March 24, 1906, thus increasing this fund to exactly $10,000.00 par value, half of which yields 6 per cent interest and the other half 5 per cent, or a total of $550.00 annually. The entire cost of the Publication Fund was $9,342.50, so that the rate of interest on the actual investment is nearly 6 per cent. The total interest received during the year from these permanent investments ($517.33), increased by that ($64.38) on monthly balances from the Security Trust Company of Rochester, New York, amounts to $581.71, while $120.00 more will accrue (on the 40 shares of the Ontario Apartment House Company stock) January 1, 1907.

A table showing the growth of the Publication Fund and these interest items from the beginning of the Society's financial history will prove both instructive and useful.

The first purchase on account of permanent investments was made during the incumbency of my predecessor in the Treasuryship, Professor H. S. Williams, on April 1, 1891, when a $1,000.00 seven per cent bond of Tioga township, Kansas, was bought at a cost of $1,140.25; so that when the present Treasurer assumed the office, January 1, 1892, the in-

vested funds had a par value of $1,000.00 and an annual interest return of $70.00.

The following table exhibits the growth of the invested funds and interest items, the latter being increased each year to a small extent by the 4 per cent received on monthly balances from the Security Trust Company of Rochester, New York, where all the cash not needed in paying current accounts has been kept for the last 15 years:

Year.	Cost of investment.	Par value.	Annual interest from investments.	Interest on bank balances.
1889	....	....	....	$16 63
1890	....	....	....	51 34
1891	$1,140 25*	$1,000 00*	$35 00	65 32
1892	900 35†	900 00†	92 50	16 72
1893	700 00†	700 00†	135 50	17 65
1894	....	....	135 50	23 46
1895	304 00‡	300 00‡	162 00	8 06
1896	....	....	168 00	23 00
1897	100 00†	100 00†	170 50	49 84
1898	1,976 25	2,000 00	275 50	32 98
1899	....	....	273 00	60 28
1900	....	....	273 00	97 23
1901	1,000 00	1,000 00	282 63	100 61
1902	....	....	236 11	151 83
1903	2,000 00	2,000 00	248 00	148 17
1904	2,366 25	3,000 00	483 00	93 98
1905	1,000 00	1,000 00	448 00	65 64
1906	1,000 00	1,000 00	517 33	64 38
Total	$12,487 10	$13,000 00	$3,935 57	$1,087 12

Adding the total of interest received on investments, $3,935.57, to the total received from bank deposits, $1,087.12, gives a grand total of $5,022.69 received since the organization of the Society, all of which except $168.27 has been received during the last 15 years.

At the second annual meeting of the Society, held in New York city, December 26, 1889, the Council, among other recommendations, asked that an effort be made to raise a Publication Fund of $10,000.00. This demand not having been met, the Council renewed the request in submitting its annual report at the Columbus meeting of December 29, 1891. It was evidently the expectation of the Council that some wealthy friends of the Society would donate the amount requested in a short time, but the hope failed of fruition. The present Treasurer, who was elected at the Columbus meeting (1891) never made any serious effort to raise a Publication Fund in the way suggested, because he preferred to see what

* Kansas bond redeemed at $1,081.80, April 1, 1904.
† $1,700 in Cosmos Club bonds redeemed at par May 16 and 25, 1901.
‡ T., K. & F. bonds redeemed July 28, 1906, at par and accrued interest.

the Society could do for itself by careful attention to correct business methods, and hence it is with no small degree of satisfaction that the retiring Treasurer can at this meeting turn over to his successor and to the Society the full amount ($10,000.00) asked for 15 years ago, invested in first-class interest-bearing securities, with all accrued bills paid to date (except 3 bills for $572.00 just received from President) and $2,000.00 in the treasury. The above table illustrates the value of small savings and points the way to a continued increase of the Society's financial resources. The total expenses of the Treasurer's office (printing, stationery, and postage) for the last 15 years amount to $318.23, or an average of $21.23 per annum.

The securities now owned by the Society are as follows:

	Par value
March 17 and 25, 1898, two Texas and Pacific Railroad 1st mortgage 5 per cent bonds, cost $1,976.25	$2,000 00
February 6, 1901, ten shares of the capital stock of the Iowa Apartment House Co., Washington, D. C., cost $1,000.00	1,000 00
April 1, 1903, twenty shares of the capital stock of the Ontario Apartment House Co., Washington, D. C., cost $2,000.00	2,000 00
April 11, 1904, three second mortgage 5 per cent bonds of the U. S. Steel Corporation, cost $2,366.25	3,000 00
May 12, 1905, ten shares of the capital stock of the Ontario Apartment House Co., Washington, D. C., cost $1,000.00	1,000 00
March 24, 1906, ten shares of the capital stock of the Ontario Apartment House Co., Washington, D. C., cost $1,000.00	1,000 00
Total cost, $9,342.50; total par value	$10,000 00

The general financial condition of the Society is exhibited by the tabular statement (page 567), showing the receipts and disbursements for the year ending December 1, 1906.

This *balance* is distributed as follows:

In the Security Trust Co. of Rochester, N. Y.	$1,678 47
In the Bank of Monongahela Valley, Morgantown, West Va.	318 94
Total	$1,997 41

Respectfully submitted.

I. C. WHITE,
Treasurer.

MORGANTOWN, WEST VA., *December 20, 1906.*

Statement of Receipts and Expenditures

RECEIPTS

Balance in the treasury December 1, 1905		$1,609 26
Fellowship fees 1903 (4)	$40 00	
" " 1904 (7)	70 00	
" " 1905 (31)	310 00	
" " 1906 (171)	1,710 00	
" " 1907 (1)	10 00	
		2,140 00
Initiation fees (16)		160 00
Life commutations (5)		500 00
Interest on investments:		
Tunnelton, Kingwood and Fairchance R. R. bonds	$18 00	
Iowa Apartment House Co. stock	60 00	
Texas and Pacific R. R. bonds	100 00	
Ontario Apartment House Co. stock	189 33	
U. S. Steel Corporation bonds	150 00	
Interest on deposits with Security Trust Company of Rochester, N. Y.	64 38	
		581 71
Investments (Tunnelton, Kingwood and Fairchance bonds) redeemed		301 50
Sales of publications		736 25
Total receipts carried forward		$6,028 72

Total receipts brought forward		$6,028 72

EXPENDITURES

Secretary's office:		
Administration	$157 92	
Bulletin	207 05	
Allowance	500 00	
		$864 97
Treasurer's office:		
Postage		17 50
Librarian's office		8 71
Publication of Bulletin:		
Printing	$1,392 13	
Engraving	494 45	
Editor's allowance (personal and office expenses)	250 00	
		2,136 58
Investments, ten shares Ontario Apartment House Co. stock		1,000 00
Miscellaneous		3 55
Total expenditures		4,031 31
Balance cash on hand December 1, 1906		$1,997 41

EDITOR'S REPORT

To the Council of the Geological Society of America:

The Editor was able to make only a preliminary report to the Council at the meeting held in December, 1906, but full statistics were prepared for both volumes 16 and 17 before the latter volume was closed.

J. STANLEY-BROWN,
Editor.

	Average. Vols. 1–12.	Vol. 13.	Vol. 14.	Vol. 15.	Vol. 16.	Vol. 17.	Vol. 18.
	pp. 577. pls. 43.	pp. 583. pls. 58	pp. 609. pls. 65.	pp. 636. pls. 59.	pp. 636. pls. 94.	pp. 785. pls. 84.	pp. 717. pls. 74.
Letter-press	$1,575 14	$1,647 12	$1,657 50	$1,661 21	$1,817 03	$2,087 98	$2,015 68
Illustrations	327 62	477 27	431 21	457 76	706 97	608 68	$486 22
	$1,902 66	$2,124 39	$2,088 71	$2,118 97	$2,524 00	$2,696 66	$2,501 90
Average per page	$3 30	$3 64	$3 43	$3 33	$3 96	$3 37	$3 42

Classification

Volume.	Areal geology.	Physical geology.	Glacial geology.	Physiographic geology.	Petrographic geology.	Stratigraphic geology.	Paleontologic geology.	Economic geology.	Official matter.	Memorials.	Unclassified.	Total.
	Number of pages.											
1	116	137	92	18	83	44	47	.....	60	4	4	593 + xii
2	56	110	60	111	52	168	47	9	55	1	7	662 + xiv
3	56	41	44	41	32	158	104	.....	61	15	1	541 + xii
4	25	134	38	74	52	52	14	.....	47	32	2	458 + xii
5	138	135	70	54	28	51	107	.....	71	14	9	665 + xii
6	50	111	75	39	71	99	1	.....	63	25	4	538 + x
7	38	77	105	53	40	21	123	4	66	28	13	558 + x
8	34	50	98	5	43	67	58	14	79	8	....	446 + x
9	2	102	138	.....	44	28	64	16	64	12	....	460 + x
10	35	33	96	37	59	62	68	28	84	27	17	534 + xii
11	65	110	21	10	54	31	188	7	71	60	46	651 + xii
12	199	39	55	53	24	98	5	5	70	2	....	538 + xii
13	125	17	13	24	28	116	42	4	165	32	29	583 + xii
14	48	47	48	59	183	118	22	1	80	14	1	609 + xii
15	26	124	3	94	36	267	.....	.....	77	17	3	636 + x
16	64	111	78	30	102	141	19	.....	67	22	15	636 + xii
17	49	161	41	84	47	294	27	.....	71	9	2	785 + xiv
18	16	164	141	5	29	246	5	.....	68	40	3	717 + xii

COLD SPRING HARBOR, N. Y., *December* 20, 1907.

Librarian's Report

To the Council of the Geological Society of America:

Accessions to the Library for the past year were duly acknowledged and catalogued, and the list of accessions to September 1 compiled and sent to the Secretary for incorporation in volume 17 of the Bulletin.

There are now 3,000 catalogued numbers in the Library, some 2,000 of which are bound volumes, for the most part sets of the publications of the exchanges of the Society. The binding, which is done by the Case Library, amounts to about 125 volumes a year.

The expense of this office the past year is as follows:

To postage	$1 46
To express	2 25
To clerk hire	5 00
	$8 71

Respectfully submitted.

H. P. Cushing,
Librarian.

Cleveland, Ohio, *December 1, 1906.*

On motion of the Secretary, it was voted to defer the consideration of the Council report to the following day.

As the Auditing Committee to examine and report upon the accounts of the Treasurer, the Society elected A. P. Coleman and N. M. Fenneman.

ELECTION OF OFFICERS

Acting President Davis then announced the result of balloting for officers for 1907, as canvassed by the Council, and declared the following officers elected.

President:

Charles R. Van Hise, Madison, Wis.

First Vice-President:

J. S. Diller, Washington, D. C.

Second Vice-President:

A. P. Coleman, Berkeley, Cal.

Secretary:

Edmund Otis Hovey, New York city.

Treasurer:

William Bullock Clark, Baltimore, Md.

Editor:

Joseph Stanley-Brown, Cold Spring Harbor, N. Y.

Librarian:

H. P. Cushing, Cleveland, Ohio.

Councilors:

H. E. Gregory, New Haven, Conn.

H. F. Reid, Baltimore, Md.

ELECTION OF FELLOWS

Secretary Fairchild stated that the candidates for fellowship had been elected by the transmitted ballots with but few dissenting votes. The list is as follows:

Alfred Ernest Barlow, B. A., M. A., D. Sc., Ottawa, Canada. Mining Geologist.

Ray Smith Basslet, B. A., M. S., Ph. D., Washington, D. C. Assistant Curator Stratigraphic Paleontology, U. S. National Museum.

Eugene Coste, B. ès-Sc., E. M., Toronto, Canada. Mining Engineer.

John Alexander Dresser, B. A., M. A., Montreal, Canada. Principal of Prince Albert School.

Russell D. George, A. B., A. M., Boulder, Col. Professor of Geology, University of Colorado.

Ellsworth Huntington, A. B., A. M., Milton, Mass. Fellow of Harvard University.

Thomas Augustus Jaggar, Jr., A. B., A. M., Ph. D., Cambridge, Mass. Professor of Geology, Massachusetts Institute of Technology.

Douglas Wilson Johnson, B. S., Ph. D., Cambridge, Mass. Assistant Professor of Physiography, Harvard University; Assistant Professor of Geology, Massachusetts Institute of Technology.

Joseph Volney Lewis, B. E., S. B., New Brunswick, N. J. Professor of Geology, Rutgers College.

Davis Hale Newland, B. A., Albany, N. Y. Assistant State Geologist.

Ida Helen Ogilvie, A. B., Ph. D., New York city. Tutor in Geology, Barnard College, Columbia University.

William A. Parks, B. A., Ph. D., Toronto, Canada. Associate Professor of Geology, University of Toronto.

William John Sinclair, B. S., Ph. D., Princeton, N. J. Instructor of Geology, Princeton University.

Arthur Clifford Veatch, Washington, D. C. Geologist, U. S. Geological Survey.

NECROLOGY

On call of the Acting President, memorials of the Fellows who had died since the Ottawa meeting were read as follows:

MEMOIR OF WILLIAM BUCK DWIGHT

BY F. J. H. MERRILL

William Buck Dwight was born in Turkey at Constantinople May 22, 1833. His father was the Reverend Harrison Gray Otis Dwight, who in 1831 settled in the Turkish capital as the first American missionary to the Armenians. His mother's name was Elizabeth Barker.

The subject of this sketch came to America in 1849 and entered Yale College, from which he was graduated with the degree of Bachelor of Arts in 1854. He then entered the Union Theological Seminary in New York and was graduated in 1856. Returning to New Haven and renewing his studies at Yale, he received the degree of Master of Arts in 1857, and two years later was granted the baccalaureate degree in Science.

This broad educational foundation was planned to support him in the undertaking which he and his elder brother had contemplated, of founding at Constantinople an unsectarian Christian institution for higher education.

This idea was, however, soon after, absorbed and developed by others, and William B. Dwight turned his energies to the field of teaching at home.

In 1859 he married Miss Eliza Howe Schneider and in the same year founded and became principal of the Englewood, New Jersey, Female Institute, in which he remained until 1865. From 1865 to 1867 he was occupied with work in mining geology in Virginia and Missouri, in the course of which he examined and reported on the now familiar Mine La Motte, and in the latter year opened a school for the children of the Military Officers at West Point, New York, which he conducted until 1870. He was then appointed Associate Principal and Professor of Natural Sciences in the Connecticut State Normal School, at New Britain. There he became actively engaged in teaching the branches to which he subsequently devoted his life, and in 1878 was called to the chair of Natural History in Vassar College, which he held until his death, in August, 1906. From 1878 to 1890 he was also in charge of the Zoological Department in the Marthas Vineyard Summer Institute, at Cottage City, and not long since was actively engaged, in cooperation with Professor N. S. Shaler, in editing the definitions in geology for the Standard Dictionary.

Shortly after taking up his residence at Poughkeepsie, Professor Dwight became interested in the geology of the surrounding district. With this began a fruitful investigation of the stratigraphy and paleontology of the limestone belts of Dutchess county, of which the age was up to that time undefined by recognized fossils, although it had been rather

generally assumed as Lower Silurian. The results of this work appeared chiefly in the American Journal of Science between 1879 and 1890 and established for the author a reputation as a most careful observer of obscure paleontologic detail. He was also the successful designer of mechanical appliances for making thin-sections of the much altered fossils of these semicrystalline rocks from which metamorphism had nearly obliterated the evidences of organic life. It was the privilege of the writer to become acquainted with him in 1885, when in the midst of success in the development of a new field of investigation, and his enthusiasm and self-sacrificing devotion to his work were such as to inspire the highest admiration.

At the time when Professor Dwight took up his work it was commonly considered by trustees of colleges that only chemists and physicists were entitled to laboratories and apparatus; other workers in science were supposed to elaborate their conclusions chiefly from the alcoves and dust of the college library. It was therefore at that time a more strenuous undertaking to accomplish the result in question than to do similar work in these enlightened days of more liberal allowances for college work in science. As a teacher, Professor Dwight filled a wide field and will long be remembered as a strong and beneficent influence in the progress of natural science. He was content to give much of his time to elementary instruction, but will prove to have been of broader helpfulness than some who have specialized in higher branches of geology.

His end, which came at Cottage City, Massachusetts, on August 29, 1906, was sudden, peaceful, and probably painless, perhaps the best that one can desire. Three children survive him with the comfort of an honored father's name.

MEMOIR OF SAMUEL LEWIS PENFIELD

BY JOSEPH P. IDDINGS

Samuel Lewis Penfield, known to the world of science as mineralogist and investigator, remembered by hundreds of graduates of the Sheffield Scientific School as the Professor of Mineralogy and Instructor in Blowpipe Analysis, was to his colleagues and friends a genial and lovable companion, whose cheerfulness, generosity, steadfastness, and absolute honesty in thought and action form his most memorable characteristics.

Born in the village of Catskill-on-the-Hudson on January 16, 1856, his boyhood was spent at home, in attending school and in the enjoyment of such sports as a boy may find on the river or the neighboring mountains. His father, George H. Penfield, was a shipping merchant, prominent in business and in religious affairs, a man noted for his generosity

Samuel L. Penfield

and given to hospitality. His mother was Ann A. Cheesman, of Connecticut ancestry. By inheritance and early training he acquired that cheerful and amiable spirit which made him so companionable, and those generous and sympathetic impulses that bound him so closely to his friends. From them also sprang that native honesty which was the foundation of his character, underlying his judgment, occasioning his frankness and sincerity of speech, and forming the controlling element of his scientific work. To them must be ascribed that simple and unfaltering confidence in a beneficent Deity which accompanied him through life and permitted him to endure the strain of his prolonged illness with cheerful patience and Christian courage.

While yet a boy his fondness for study led him to hope for a college education and caused him to go to the academy at Willbraham, Massachusetts, to prepare himself for the Sheffield Scientific School, which he entered in the autumn of 1874. His tastes and talents led him to success in mathematics and the natural sciences, and at the end of his freshman year he selected the course in chemistry. In this he distinguished himself as an analyst, graduating with honors in 1877. To his classmates he was a modest, manly comrade, devoted to his studies and enthusiastic in his laboratory work.

Upon graduating he became an assistant in the chemical laboratory of the Sheffield Scientific School, and in addition to his duties as an instructor occupied himself with analytical work, especially on mineral compounds. His first publication is dated the year of his graduation and is on "The chemical composition of triphylite from Grafton, New Hampshire." His career as a mineralogist must be considered the natural result of his environment, for there was an invigorating atmosphere about the place like the clear, brilliant air that surrounds the summits of mountains. The young, enthusiastic investigator felt the inspiration that came from his association with such men as George J. Brush, James D. Dana, Edward S. Dana, and George W. Hawes, men of clear cut, vigorous ideas and brilliant attainments. It acquired specific direction through the opportunity offered him for cooperation with Professors Brush and E. S. Dana in their study of the remarkable group of minerals found in the pegmatite at Branchville, Connecticut. The analytical chemical work was intrusted to him in part, and he determined the composition of five new species of magnesian phosphates, eosphorite, triploidite, dickinsonite, fairfieldite, and fillowite, that of two other new species being determined by his classmate and associate in the chemical laboratory, Horace L. Wells. In addition to these he analyzed a number of other minerals from this locality and from elsewhere. About this time

also he contributed to the improvement of analytical processes, publishing in 1879 a paper "On a new volumetric method of determining fluorine."

It appears that up to this time his interests were centered in the purely chemical phase of his work, and it is doubtful whether he looked upon the study of mineralogy as the probable occupation of his life, for in 1880 he went to Strasburg to attend the lectures and laboratory of Professor Rudolph Fittig for the purpose of acquiring advanced methods of work in organic chemistry. He also attended some of the lectures in mineralogy given by Professor P. Groth. While in Strasburg he published, with Professor Fittig, a paper on some of the hydrocarbon compounds investigated in his laboratory.

Whatever may have been his intention at this time, his course as a mineralogist was determined upon his return to New Haven, in the autumn of 1881, by the opportunity offered him to become instructor in mineralogy in the Sheffield Scientific School in place of Doctor George W. Hawes, who had been called to Washington, D. C., to take charge of the geological department of the National Museum.

Assuming the responsibilities of this position four years after his graduation, he threw into the work of the course in determinative mineralogy and blowpipe analysis all the energy and enthusiasm of his nature, injecting into the laboratory methods the skill and precision that characterize his own analytical operations. At first his interest in mineralogy was chiefly in its chemical side, since the work with the students largely involved the chemically determinative phase of the subject, and his publications continued to treat of the chemical composition of various minerals; but an increasing interest in the physical properties of minerals and in their crystallography led him in 1884 to go to Germany for the second time, and to study with Professor Rosenbusch at Heidelberg the methods of investigation so successfully employed by him in the petrographical laboratory. This experience was followed by a broadening of his methods of work and of the range of his investigations, so that the physical characters of minerals, especially the optical properties and the crystal form, were studied, in addition to their chemical composition. In these operations he developed the same skillfulness of manipulation and thoroughness which characterize his chemical work.

In 1886 he became responsible for all of the mineralogical instruction given in the Sheffield Scientific School, owing to the fact that the school had increased to such a size as to require in its management all of the time and energy of its director, Professor Brush. In 1888 Penfield was appointed assistant professor, and in 1893 he was created a professor, and in consequence became a member of the governing board of the Sheffield Scientific School.

His success as a teacher followed from his devotion to the work and his personal interest in the individual student, and particularly from his painstaking efforts to aid the student in every way by presenting the subject in the simplest manner and by assisting the imagination by ingenious models and devices for illustrating crystal forms and structures. His success was also due to his systematic and thorough methods of work, and to a considerable extent undoubtedly to his great patience, persistency, and amiability.

That he succeeded in imparting his zeal and enthusiasm as well as his skill to those who worked in his laboratory as advanced students is shown by the successful mineralogists who have been trained by him. Evidence of his thought and ingenuity in the arrangement of his collections and apparatus is furnished by the appointments of the mineralogical laboratories in Kirtland Hall, which was built three years before his death; and it is a source of great satisfaction to his friends, as it was of happiness to himself, that the last two years of his life were spent in the enjoyment of his ideal of a mineralogical laboratory.

That he fulfilled successfully his obligations as a teacher and also achieved yet greater fame as an investigator was due to his extreme diligence as a worker, devoting to his studies all of his reserve of time and energy; and it was also due to his clear comprehension of mineralogical problems and to his ability to execute with deftness and ease the mechanical operations required in their solution. The latter showed itself in the manipulation of apparatus, whether in chemical analysis or in optical or crystallographic determinations, in which he became especially interested. He was for these reasons not only able to accomplish much in comparatively short periods of time, and thereby traverse a wide field of operation, but he obtained astonishingly good results from what might have proved inadequate material in less skillful hands. Some of his chemical analyses were carried out successfully on very small amounts of mineral, in one case upon one-tenth of a gram, and some of his crystallographic measurements were made on surprisingly small crystals. The uniformly high quality of his work, as already said, is due to his absolute honesty and conscientiousness. The exact facts and all of them that could be obtained by any means at his command were the least that would satisfy the demands of his nature, though of this exaction he was himself probably unconscious. It was an exaction applied to his work and did not extend to his general intercourse with others, toward whom he was always lenient, even indulgent.

Much of his work was done in cooperation with others, chiefly his laboratory assistants or graduate students, and he was generous in his

treatment of them and in the recognition of their work. He was also a liberal assistant of other investigators, whom he helped by advice or by contributions of analytical or of other determinative work.

In 1898 he published a revised and almost completely re-written edition of the Manual of Determinative Mineralogy and Blowpipe Analysis, originally the work of Professor George J. Brush. The list of publications include over eighty titles, all of which are distinct contributions to the science of mineralogy or chemistry. Their value consists in part in being determinations of new species; in part in being corrections based on more exact analyses of numerous species whose composition had been previously imperfectly and unsatisfactorily determined. Of the entirely new mineral species which were described by him, there are fourteen, namely, bixbyite, canfieldite, clinohedrite, gerhardtite, glaucochroite, graftonite, hamlinite, hancockite, leucophœnicite, nasonite, nesquehonite, pearceite, roeblingite, and spangolite. There are twenty-one species whose correct composition he was able to establish: alurgite, amblygonite, argyrodite, aurichalcite, childrenite, chondrodite, clinohumite, connellite, cookeite, ganomalite, hanksite, herderite, howlite, humite, monazite, ralstonite, staurolite, sulphohalite, topaz, tourmaline, and turquois.

His last investigative work, which was being carried on in association with Mr F. S. Stanley, was aimed at the elucidation of the problem of the composition of the amphiboles.

Among his specific achievements may be mentioned the recognition of the isomorphic rôle played by fluorine and hydroxyl in the structure of numerous minerals and the consequent necessity for their recognition in the composition and formulæ of such minerals; also the determination of the relations between the proportions of these constituents in a mineral series and the physical properties of the minerals, as in topaz and in the members of the humite group—humite, chondrodite, and clinohumite.

Another important achievement was the recognition of germanium in a silver ore from Bolivia and the correct crystallographic determination of the mineral argyrodite, in which the element was first discovered; also the demonstration of the control exerted upon the character of the crystal symmetry in such a chemically complex mineral as tourmaline by the acid portion of the molecule, which appears to be largely independent of the nature of the bases combined with the acid.

His contributions to crystallography consist not only of numerous accurate determinations and descriptions of crystal forms, but in the elaboration of graphical methods of representing crystals and of calculating angular relationships and also in devising simple drawing instruments and maps for use in spherical projection. His studies in these methods

led him to advocate the application of stereographic projection to geographical map making and to demonstrate the advantages to be derived from its use.

He did not confine his investigations and experiments to his laboratory, but broadened his horizon by working in the field, spending two summers in the Yellowstone National Park as an assistant on the United States Geological Survey, and other summers in New York state, North Carolina, and Colorado, as well as in various parts of Europe, visiting at the same time the most celebrated mineral collections and becoming acquainted with foreign mineralogists.

The high quality of his work and the value of his contributions to the science of mineralogy are attested by the esteem in which he was held both abroad and in his own country, as well as by the honors bestowed upon him. Beginning with the year 1893, these rapidly succeeded one another in the following order: Associate Fellow of the American Academy of Arts and Sciences in Boston; in 1896, Foreign Correspondent of the Geological Society of London, Master of Arts in Yale University; in 1900, Member of the National Academy of Sciences; in 1902, Fellow of the American Association for the Advancement of Science, Corresponding Member of the Royal Society of Sciences at Göttingen, Member of the Scientific Society of Christiania; in 1903, Corresponding Member of the Geological Society of Stockholm and Foreign Member of the Mineralogical Society of Great Britain. In 1904 he received the honorary degree of Doctor of Laws from the University of Wisconsin. He was a member of the Connecticut Academy of Sciences and a fellow of the Geological Society of America.

These honors he accepted with such charming modesty that many of them remained hidden and unsuspected by even those most intimate with him. His achievements followed as the natural results of his ceaseless activities, which sprang from a love of research for its own sake.

For twenty years after his graduation he remained unmarried, devoting his time, thought, and energy to his scientific work. During the greater part of these years he lived with a small company of bachelor colleagues in the attic of Sheffield Hall, familiarly known as "Old Sheff"; here his genial and generous nature won him the admiration and affection of his associates and friends. In these homely halls, low-roofed and bare, there grew up a group of men who seem to have acquired from their surroundings certain sturdy qualities which are to be reckoned among their fortunate characteristics.

In 1897 Professor Penfield married Miss Grace Chapman, of Albany, who brought to him great happiness, and whose devotion to him through

the years of his illness strengthened his courage and undoubtedly prolonged his life.

As the man is more than his achievements, so the character of Samuel Lewis Penfield must be accorded higher praise than his labors. Honest, and modest, and true; sympathetic, and generous, and loving; steadfast and simple in his affections and in his beliefs, his beneficent nature has affected the lives of many who have come within its influence, and, being transmitted beyond the range of his own experience, will contribute its share to the sum of human goodness. And, as his works and writings will be found in print long after his personality shall have faded from the minds of men, may this suggestion of his noble character be found in place beside the record of his accomplishments.

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* This list has been taken from the memoir published by Professor L. V. Pirsson in the *American Journal of Science*, fourth series, vol. xxii, 1906. It has been revised by Professor H. L. Wells, and is believed to be practically complete.

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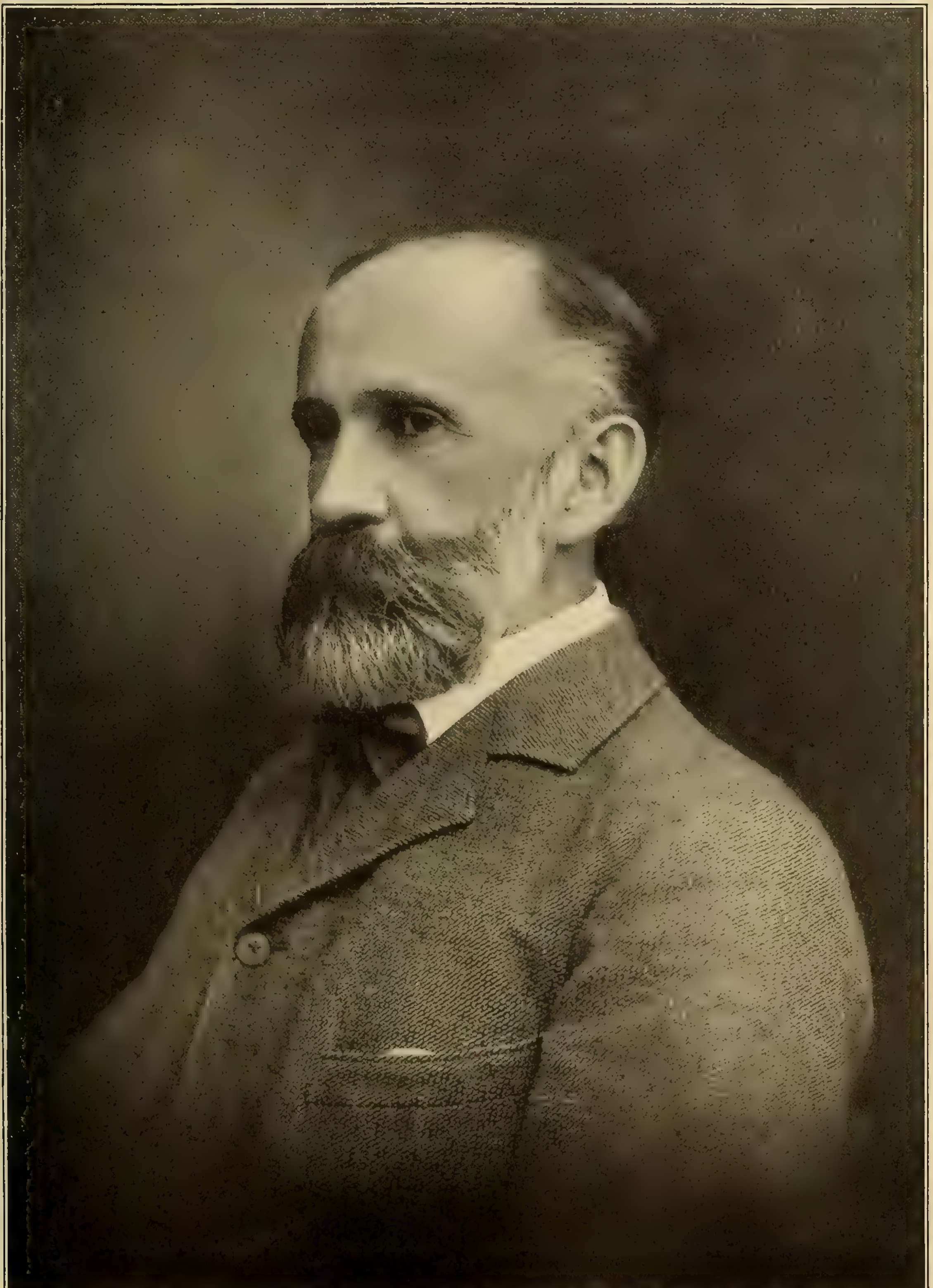
MEMOIR OF ISRAEL C. RUSSELL

BY BAILEY WILLIS

A native of New York by birth, Israel C. Russell was at home everywhere, through the intrepidity of his spirit and the breadth of his interests. The arid plains of our West, or the snowy scarps of Saint Elias, or the ash-strewn slopes of Pelée were to him equally alluring. The unexplored challenged the inborn instinct of the explorer, which dominated the aims of his life; he delighted to attempt the unknown; he was independent and at ease in the wildest environment; and where in the interest of science difficulty or danger were to be met, there he was most resourceful, cool, and happy. On the other hand, he was restless under routine; he chafed in harness; he rather endured than enjoyed the comforts of conventional life, with the obligations they imposed.

It is told of a colonial Russell ancestor that when calling Sunday evenings on the lady whom he afterward married he would confine his remarks to a greeting and a phrase of thanks on leaving for the pleasant visit he had enjoyed. Silence ran in the family, but so also did a genial sense of the pleasure of conversation. Outwardly the Russell we knew was a silent, self-contained man, from whom flashed occasionally a sally of keen wit; but the external reserve covered a fertile mind and a warm kindly



Israel C. Russell

nature. In the exchange of scientific thought he gave generously; in the field he was a considerate and loyal comrade, as men near and true to Nature are; and in his home, in those intimate relations that are the highest test of character, he has left a memory which sustains his family and is a heritage of love and inspiration for his children.

Russell's career falls into four epochs, through all of which runs the chain of exploration. After graduating from the University of New York in 1872, he sought an opportunity to accompany the U. S. Transit of Venus expedition to New Zealand in 1874 and 1875, and finding the opportunity limited to the position of photographer, he learned the then difficult art and received the appointment. This journey around the world opened to him the great field of physical geography in which he afterward labored continuously. He drifted for five years after his return. Two years as assistant professor of geology at Columbia, a season in New Mexico, a journey to Europe—these completed the first epoch of restless preparation. When I was a student in Columbia he was constantly at work among the collections—a slender, silent figure, a typical student, in whom one would not suspect the power of initiative, the capacity for daring and doing, which characterized the man.

The second epoch covered the years from 1880 to 1885, during which, as geologist of the U. S. Geological Survey, in association with Gilbert, he studied the Pleistocene history of the Great basin. Here he was in his element—free, face to face with Nature, and in frequent intercourse with one who may be characterized as one of the wisest organizers of American geologic science of any period. While Gilbert interpreted the history of lake Bonneville, Russell developed that of lake Lahontan; the two studies ran parallel and reacted each upon the other. The senior's influence is seen in the character of the Lahontan monograph, which is a systematic, complete, and essentially final work, peculiar among Russell's writings in being thus highly organized and finished; but the acute observations regarding the chemical history of the waters and its bearing on variations of the lake are Russell's independent contribution.

When in 1885 Gilbert surrendered his promising investigations of the Great basin to undertake the study of the Appalachian province, Russell was also transferred and their association continued. Cogent as the administrative reasons for the transfer were, the change of tasks was unfortunate for the scientists and for science. Gilbert was burdened with executive affairs, and Russell found in the southern Appalachians an uncongenial field. Nevertheless he worked with characteristic activity and completed the investigation of the section assigned him in Gilbert's systematic plan for studying the Appalachians; but he did not bring the

work to a condition for publication and it was inherited by Hayes. Several of the folios are still unpublished on account of the difficulty of working out the metamorphic rocks.

Russell's earliest geologic studies had been on the Triassic rocks of New Jersey and Connecticut, and they were continued on his return to the East in North Carolina and Virginia. When Powell planned the correlation papers he was the best equipped man available for the Triassic. He extended the fieldwork in 1888-1889, visiting the sections in the far West, but was interrupted by an assignment to exploration in Alaska. His observations beyond the eastern districts being thus left incomplete, the correlation essay was confined to the Newark formation. It is a carefully prepared abstract of the literature, accompanied by original chapters on the stratigraphy, paleontology, diastrophism, and degradation of the formation. Later studies have contributed additional details of stratigraphy and structure of the Newark, but they have not modified Russell's conclusions in regard to its former distribution and the geographic conditions of the epoch.

A logical development of his studies of western Pleistocene was the investigation of subaerial decay of rocks, and the Triassic invited his attention directly to the cause of the red color in certain deposits.

Thus closed the third epoch of his career, during which he worked against his inclination and reaped but little result from nearly four years of industrious application to the tasks assigned him.

Alaska was a field which was the antithesis of the Appalachian for a man of Russell's abilities. He first visited it in 1889, as the representative of the U. S. Geological Survey on the expedition of the U. S. Coast and Geodetic Survey to determine the boundary with British Columbia. After many weeks of steamer travel through the Yukon flats, with little chance for geology, he cut loose from the expedition on the upper Yukon and with three miners came out across the ranges to the coast. Alert to observe the features of stratigraphic and surface geology, he made the most of the somewhat limited opportunity and contributed valuable observations on the general structure of the Yukon basin and the limitations of Pleistocene glaciation. His article on the surface geology of Alaska lays down for that subject the principal lines of investigation which have since been elaborated by others.

Mount Saint Elias, then supposed to be the highest peak in United States territory, had for several years been the pole of Russell's purpose. His imagination was fascinated by the snowy heights that rise in alpine grandeur near the sea, yet remained untrodden. In contrast with this inaccessible pinnacle of unknown geologic interest, the rich fields of

geology within easy reach had no attraction for him. Better an hour on that frost-fettered virgin height than a year in the haunts of men. Through the cooperation of the National Geographic Society and the U. S. Geological Survey, his purpose of exploration was realized and he twice visited the region. He did not attain the highest summit, being driven back repeatedly by storms, and the last time when all the difficulties of the ascent had been overcome; but he yielded only to irresistible conditions and made a record of indomitable pluck and perseverance. The experience which he gathered at cost of extreme effort and risk he placed freely at the service of others, and a share in the honor of the successful ascent made by the Duke of the Abruzzi is justly granted by the latter to Russell.

In the course of his second expedition Russell was separated from his companions on the slopes of mount Saint Elias and proceeded alone to a camp they had established above the ice cascades of the glaciers beneath the cliffs that define the peak. The others were to join him there, but a heavy storm interfered and Russell was isolated among the wildest scenes of alpine crags and ice. His tent was crushed and he burrowed in the snow, where he measured out his scant supplies into eight days' rations and prepared himself to await the issue. Afterward, in discussing Chamberlin's suggestion that heat waves might be transmitted through glacial ice, he once remarked that none penetrated the snowbank in which he passed three days. Storm winds whirled through the amphitheater; avalanches shot from the cliffs; the isolation was utter and to many men would have been terrible; but Russell's was a spirit that rose with the battling elements and exulted in challenging Nature's most savage mood.

The expeditions to Saint Elias were made across the Malaspina, the great confluent glacier which receives the alpine ice-streams of the range and extends to the coast, where it is in part covered by primeval forest. The opportunity to study glacial phenomena was unrivaled and was fully exploited by Russell, who thus by direct observation made us acquainted with the piedmont type of ice-sheet, which was formerly of common occurrence throughout the northern hemisphere.

The exploration of mount Saint Elias was the most striking, but not the most fruitful of Russell's campaigns against the unknown. He continued his sallies into unexplored regions during the years following 1901, going out each summer, as the vacation season permitted. He repeatedly made reconnaissances in Washington, Oregon, and Idaho for the U. S. Geological Survey, and there are extensive areas which we know only through his publications.

In 1892 Russell succeeded Alexander Winchell in the chair of Geology

at the University of Michigan and established his home at Ann Arbor. Five years previously (1887) he had married Julia Augusta Olmstead, who, with their three daughters and one son, survives him. The home circle was one in which it was a happy privilege to be welcomed, and in that atmosphere Russell, talking of glowing scenes of the deserts and snow peaks he knew so intimately, revealed beneath the quiet exterior the enthusiasm of an artist.

Russell's place in science was determined by the epoch in which he lived and by the strong impulses of his own nature. The conditions of the one and the tendencies of the other were in harmony when he began his career; later the conditions changed, but Russell did not, except in outward compliance, and he remained ever a frontiersman of science.

In the eighteen seventies American geography and geology were still sciences of exploration; the refinements of surveying were undeveloped; the specialization of the general subject had scarcely begun. The Fortieth Parallel Survey, which is now regarded as high grade reconnaissance work, was the standard piece of geologic surveying. Geology was a relatively simple study, which offered vast opportunities to keen observers and explorers, but made relatively slight demands upon the systematist and the specialist. The opportunities were those which Russell was most able to exploit brilliantly; the demands he could afford to overlook; and throughout his career he always sought the fresh opportunity, he did his best work in virgin fields. He takes his place in the group of geographers and geologists, of whom it suffices to name Newberry, Hayden, Powell, and Richthofen—men who did pioneer work, which is the essential foundation of later research; men who have blazed out the way, both physically and intellectually, for the road-builders who follow; men to whom all honor is due for the courage and high purpose they had in the face of difficulties, and to whom we owe a debt of gratitude for the greater opportunities they have opened to us.

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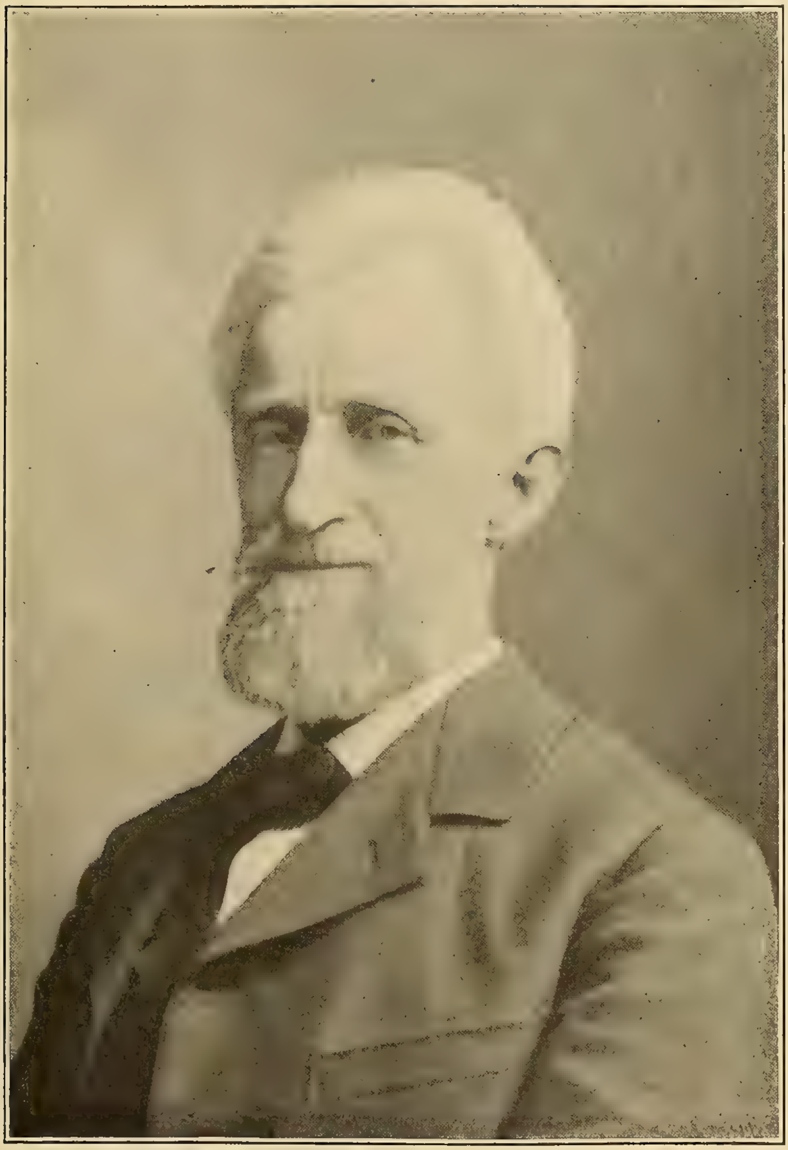
MEMOIR OF NATHANIEL SOUTHGATE SHALER

BY JOHN E. WOLFF

Nathaniel Southgate Shaler was born at Newport, Campbell county, Kentucky, February 20, 1841, and died in Cambridge, Massachusetts, April 10, 1906. His father's people migrated from England to Jamaica, and from there to New York state and Connecticut. His father, Doctor Nathaniel Burger Shaler, graduated from Harvard College in 1827 and from the Medical School in 1829; he then went to Cuba, and from there to Newport, Kentucky, opposite Cincinnati, where he settled and practiced his profession. He married Ann Hind Southgate, of a prominent family of that name, of Virginia origin. Doctor Shaler was not only a highly educated man in the usual sense, but he had a taste for natural history



There is a world of work on hand.

Faithfully yours,

N S Shaler

and knew something of geology. He owned what we might call an experimental farm a few miles from Newport, where in his spare time he cultivated new varieties of seed, tobacco, and grapes, and also experimented with breeds of sheep. The son was much about with his father in the open, often galloping out to the farm from town on a pet mare, and was encouraged by his father in making experiments of his own with plants and in collecting specimens interesting to a boy, such as minerals, arrowheads, and so on. The boy's health was delicate, so his school attendance was irregular and his formal training was acquired from a learned German named Escher, with whom his studies were of the philosophic and literary kind. From his mother he inherited his intense energy and quickness of repartee, and from her father he absorbed much of general culture, for his grandfather was a good Greek and Latin scholar, of a wide acquaintance with things intellectual, to whose discerning talk the boy listened eagerly. Thus he grew up constantly in the open and trained in out-of-door accomplishments, familiar with plants and animals and loving Nature, while at home his appreciation for the things in books was growing under this personal environment.

Young Shaler entered the Lawrence Scientific School in 1859, when 18 years old, registering in the course in zoology and geology, under Louis Agassiz, whose fame attracted students from the entire country. Among his classmates are found the names of Alexander Agassiz, Daniel C. Eaton, Alpheus Hyatt, F. W. Putnam, A. E. Verrill, Burt G. Wilder, A. S. Bickmore, A. S. Packard, and others, men who have spread the study of natural history in this country. While a student, he with Verrill and Hyatt made an excursion in 1861 to the island of Anticosti, studying the geology and collecting fossils, the first of his many wanderings over the surface of North America. He received his degree of B. S. in 1862, when 21 years old; but, without waiting for commencement, enlisted in the Federal army in Kentucky and was commissioned as captain of the Fifth Kentucky battery, called "Shaler's," and served two years, mainly in Kentucky. A volume of poetry published since his death deals with this phase of his life. Returning in 1864 to the Museum of Comparative Zoology, he was appointed "Assistant in Paleontology," with general charge, under Louis Agassiz, of that department. In this year, when 23 years old, he began his first public course of lectures at the Museum, on the "Geological succession of the brachiopoda" and on the "Elevation of continents." In 1866 he was obliged to suspend his work, owing to ill health, and spent over a year traveling in Europe, visiting many museums, seeing classical geological districts, and meeting such men as Darwin, Lyell, and Elie de Beaumont.

An incident illustrating Mr. Shaler's love of fun is that when calling on Darwin he brought with him a spirited American cartoon representing the old ape instructing the youthful Darwin, which delighted the great naturalist.

Soon after resuming his work at Cambridge he received his first formal appointment from the corporation of Harvard College as "Lecturer on paleontology and animal life considered in its geological relations," and a year later, in 1869, when 28 years old, was appointed "Professor of Paleontology" (changed in 1888 to "Professor of Geology"). His second exploration, namely, an excavation for fossil bones at Big Bone lick, Kentucky, was made in 1868; and now, besides giving lectures to undergraduates in zoology and paleontology, he began to supplement Louis Agassiz's lectures in geology by field excursions. Gradually the latter turned over to him much of the instruction in these subjects as ill health or his many undertakings necessitated.

A third excursion was made with students in 1870 to the James river, Virginia, and to other states to collect fossils. Resigning to others instruction in zoology, Professor Shaler now concentrated his teaching on paleontology and geology, especially the latter, and, having seen the establishment of the Summer School of Zoology at Penikese in 1873, he inaugurated the first summer school of geology himself, with the famous session of 1875, at Cumberland Gap, Virginia.

In 1873 he was appointed State Geologist of Kentucky, retaining this office seven years. The original survey, begun in 1854 by David Dale Owen, had lapsed, most of the records had been destroyed by fire, and nearly all of the assistants had passed away, and yet it was specified in the law establishing the new survey that it should begin where Owen's left off. This appealed to Mr Shaler's sense of humor, but he proceeded to carry out the plan as far as he could. The results are shown in five volumes, published under his direction, dealing with the resources, geology, and natural history of the state. During the years of this directorship he spent his summers largely in Kentucky and adjacent parts of Virginia, permitting a number of advanced students of geology to accompany the survey parties, who not only paid their own expenses, but often assisted in the work in any humble way permitted and were proud of the privilege. At the same time the geological department which he had founded at Harvard was rapidly growing and William M. Davis began to take a share of the instruction.

In 1881–1882 Shaler was in Europe, spending part of the time in Italy. Soon after his return he became one of the commissioners for the topographical survey of Massachusetts, which, in cooperation with the U. S.

Geological Survey under Major Powell, soon completed the topographical map of the state.

In 1884 Professor Shaler was appointed in charge of the Atlantic Coast Division of the National Survey and continued this connection until 1900, in the last seven years as a separate party. The original field of this division included the investigation of coastal lands, changes of level, phosphate beds, bog ores, etc., near the coast, but it soon broadened to cover many areas of rock geology, especially the Mount Desert island, the Narragansett coal-field and adjacent territory, and the Richmond, Virginia, coal-field. The surface geology of nearly the whole of New England was ultimately included; so that in the sixteen years of his connection with the U. S. Geological Survey he and his associates contributed many large and small papers to the annual reports and bulletins of the Survey and to outside publications.

In connection with this and earlier work done for the Coast Survey, Mr Shaler used to say he had traveled on foot nearly the whole coastline from Maine to Florida, which a hearer who was familiar with his long strides had no difficulty in believing. He made two explorations of the Dismal swamp, a trip through the marsh district about the mouth of the Mississippi, and a visit to the swamps of Michigan, Wisconsin, Minnesota, and Dakota.

In the winter of 1887–1888 he went to Florida, examining the phosphate beds southerly from Charleston, and then the Everglades and 360 miles of the east coast of Florida. On this trip the boat in which the party were sailing capsized during the night near an uncharted reef. The shore was reached with the greatest difficulty, and then followed a long walk to the nearest habitation. Mr Shaler published an article on this unexpectedly discovered reef.

Among his more important Survey publications resulting from this period may be mentioned:

In 1885: "Preliminary report on seacoast swamps of the eastern United States."

1888: "Report on the geology of Marthas Vineyard."

1889: "The geology of Cape Ann, Massachusetts;" "The geology of the island of Mount Desert," and "The geology of Nantucket."

1890: "General account of the fresh-water morasses of the United States, with a description of the Dismal Swamp district of Virginia and North Carolina."

1892: "The nature and origin of soils."

1893: "The geological history of harbors."

1895: "Peat deposits."

1898: "Geology of the Cape Cod district."

And in joint authorship with others:

In 1888: "On the geology of the Cambrian district of Bristol county, Massachusetts."

1896: "The glacial brick clays of Rhode Island and southeastern Massachusetts."

1899: "Geology of the Narrangansett basin" and "Geology of the Richmond basin, Virginia." In the course of this work Mr Shaler discovered the Cambrian fossils of Attleboro, Massachusetts, and the Cretaceous of Marthas Vineyard.

In this same period, in addition to his service to the state of Massachusetts in connection with the topographic map, Mr Shaler served on two other commissions, the national importance of which is for different reasons now apparent. The first was as a member of a committee of the State Board of Agriculture for the suppression of the gypsy moth. He entered with vigor into the fight against this pest, taking a prominent part in the organization of the work and in attempting to impress on the public the need of doing it in time. The second commission had a more grateful task, namely, that of improving the highways of Massachusetts, and Mr Shaler was one of the original three members of the Massachusetts Highway Commission, which in its ideals and methods of work has served as a model for other states.

I will quote from a letter of the present chairman, Mr W. E. McClintock, dealing with Mr Shaler's part in the beginning of this great movement. He says:

> "Professor Shaler was an enthusiastic advocate of good roads, and his numerous writings and talks brought a very large number of educated thinking men to the support of the movement, and to him more than to any one man is due the strong support of the commission by this class of men. His facile pen made the annual report of the commission held in such high repute that the usual editions were exhausted before the demand ceased."

The Geological Survey published a paper of his in 1895 on the geology of the road-building stones of Massachusetts and elsewhere. In this field he had organized a laboratory for physical tests of road materials, a work which was subsequently taken up by the U. S. Department of Agriculture.

In addition to such work, allied to economic geology, he at various times reported and advised on mines and quarries, and in his long list of publications are found several dealing with building stones. In the latter years he became interested in the question of working low-grade placer deposits, and finally organized and directed a large and successful undertaking of this kind in Montana. These various interests, theoretical and

practical, took him to many parts of this continent, including Cuba and Alaska, so that it would perhaps have been difficult to find any one who had seen understandingly more of the country and its people.

These travels and investigations, covering thirty-five crowded years, had been carried on simultaneously with his university duties, which were constantly growing in extent and importance.

No instructor at Harvard has held the position which Shaler did in the eyes and in the hearts of the students. His elementary course of lectures on the principles of geology ("Natural History," afterwards "Geology 4") reached the high-water mark of attendance, with between five and six hundred hearers, and many working geologists of the country can say with the writer that their first interest in natural history, especially in geology, was inspired by this elementary course. He also taught elementary paleontology and advanced geology, always aiming to present underlying principles, but with less attention to detail. It is estimated that about seven thousand students came under his direct instruction in this long term of years, probably a greater number than had before been taught this subject by any one man. Until his administrative duties prevented, he was much in the field, both summer and winter, with advanced students.

His teaching, however, was only a part of his activity in the university; for, besides the summer schools, he originated and directed many other ways of assisting the students, especially those who were strangers or were poor. He was ready with advice and sympathy, often of a material kind, for any who came to him in trouble.

The great university task and achievement of the last fifteen years of his life was the successful reorganization and development of the Lawrence Scientific School, which had been overshadowed by the development of Harvard College. Mr Shaler became dean in 1891, and vigorously took up the work of enlarging the instruction and resources and of attracting students; not only were the existing departments remodeled, but new ones were added from time to time, such as, for instance, that of mining and metallurgy, which at the time of his death had become a flourishing and well equipped department. The result was seen in an increase in attendance from 118 in 1891 to 504 in 1906. His friend, Gordon Mackaye, left his great fortune for the endowment of applied science in the university, and at the time of his death Mr Shaler was actively planning the development to follow from the application of this fund.

Mr Shaler's personality was striking and original. He was tall and well proportioned, neither slender nor stout, with erect, active carriage; he had prominent features, with large blue-gray eyes and thick hair, brushed back from his high forehead. In lecturing or speaking he rarely

used gestures, his favorite pose being to rest both hands on a book. And what *flashing* speaking that was, whether formal or informal; never hurried or undignified, but in turn impressive or humorous or picturesque and always interesting. The charm extended to all kinds of people. I have seen the rough mountaineers of the south listening fascinated to his words of explanation to the students with him. Perhaps some intuition of the kindness of heart which underlay his words and actions had to do with this, for Mr Shaler was above all a lover of his fellow-men and what concerned them; this was well expressed when in 1903 the degree of LL.D. was conferred on him by Harvard as "naturalist and humanist."

With all this activity in so many different lines, he yet found time to practice a warm hospitality at his home in Cambridge. He was married in 1862 to Miss Sophia Page, a resident of Kentucky, who with two daughters, Mrs Willoughby L. Webb and Mrs Walter L. Page, survives him. The host and hostess welcomed to their home not only those who might fairly be expected to offer some mutual entertainment, but also with true kindness the young and often bashful newcomers in the college.

Professor Shaler's publications dealing with geology and kindred topics number nearly two hundred titles besides many popular articles in the magazines. They deal with paleontology (especially in the earlier years), glaciation, mountain-building, shorelines, earthquakes, the elevation of continents, swamps and peat-deposits, soils, phosphate beds, petroleum, coal, building stones, changes of climate, caverns, and many others. He published various separate works, such as text-books and popular works dealing with various features of geology, always emphasizing the relation to man. His "First Book of Geology" was translated into Polish. His last important scientific publication, "A comparison of the features of the earth and the moon," published in 1903 by the Smithsonian Institution, with superb plates, is an interesting attempt to explain lunar features by the experience of geology. It illustrates an unexpected persistency in following certain lines of research, for his work with the telescope had been done thirty years earlier. I am told that for several years before his death he had been studying the coast charts of the world in continuation of his earlier work on shorelines and had even visited Egypt with this in mind.

Among his miscellaneous writings mention should be made of a series of philosophical essays entitled "The citizen, a study of the individual and the government;" "The individual, a study of life and death;" "The neighbor, the natural history of human contacts," and others, which deal with these subjects in an original way from the point of view of the naturalist.

Lastly, within a few years Mr Shaler ventured into the field of general literature and poetry. His drama, "Elizabeth of England," has been highly praised as a noble work of imagination and diction. A posthumous volume of poetry, "From old fields," has been mentioned.

It is too early to estimate the value of his formal contributions to American geology, of which but an imperfect account has been given, but there can be no doubt as to the immense influence he exerted as a teacher and expositor of the subject. He recognized the preeminent place accorded to him in this respect by chosing as the subject of his presidential address to this Society in 1895 "The relations of geologic science to education." It is perhaps as one of the great teachers of geology that he will be best remembered by us, and may the inspiration he gave long continue to bear fruit.

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1905. Man and the earth. New York, 1905.

After the memorials had been read the report of the Photograph Committee was deferred and the Secretary made sundry announcements regarding registration, luncheon, and division into sections for the reading of papers, on account of the long program. He stated that when the Society adjourned, adjournment would be to 9.30 o'clock Friday morning, at the American Museum of Natural History.

F. J. H. Merrill announced that the annual dinner of the Society would be held Friday, December 28, at 7.00 o'clock p m, at the "Arena" restaurant, 29 and 31 West Thirty-first street.

The Auditing Committee having raised the question as to the custody of the bonds belonging to the Society, the Acting President ruled, in the absence of Treasurer-elect Clark, that the securities were in the care of the Treasurer.

The Acting President then called for the reading of scientific papers. The first two papers on the printed program were read by title. They were

CUTTING OF THE MISSISSIPPI AND MISSOURI RIVER GORGES

BY N. M. FENNEMAN

LATERAL EROSION ON SOME MICHIGAN RIVERS

BY MARK S. W. JEFFERSON

This paper is printed as pages 333–350 of this volume.

GRADED SURFACES

BY F. P. GULLIVER

[*Abstract*]

This paper called attention to the need felt by the writer and others for a general term to use in physiographic descriptions for every "nearly level surface produced in the past or being now formed by some process of aggradation or degradation."

The writer showed that in a recent study of the complicated land forms of central Pennsylvania, as seen on a horseback trip with a pupil, no general term could be found to use for any given observed form without implying some hypothesis in regard to the origin of said land form. For purposes of reconnaissance study, there is a great need of some such general form term that will imply no genetic hypothesis in regard to its

formation. Then later, when the origin of the graded surface is determined, the appropriate genetic term may be applied.

The following terms were discussed, with references showing their uses by various writers: Terrace, grade, slope, bench, grade-level, grade-plain, peneplain, base-level, and bevel.

The conclusion was reached that some compromise must be made by physiographic writers in order to secure uniformity of usage. The choice would seem to lie between terrace, grade-level, grade-plain, and bevel. If one of these terms could be agreed upon by physiographic writers to use as a general form term, to imply no genetic hypothesis, greater clearness would result.

The next paper was read by title:

THE NEW MADRID EARTHQUAKE

BY M. L. FULLER AND E. M. SHEPARD

The following paper was then read:

PHYSIOGRAPHY OF THE LOWER HUDSON VALLEY

BY J. F. KEMP

The paper was discussed by Bailey Willis, W. M. Davis, and the author.

The next paper was

RELATIONS OF PHYSIOGRAPHY TO STRUCTURE AT MANHATTAN ISLAND AND VICINITY

BY ALEXIS A. JULIEN

The discussion was participated in by W. H. Hobbs, W. M. Davis, and the author.

The Society adjourned to Friday, as announced.

No session of the Society was held Thursday evening, out of deference to the American Association for the Advancement of Science, the retiring President of which, Professor C. M. Woodward, delivered the annual address at eight o'clock. This address was followed by a reception tendered by Columbia University to all the visiting scientists. The reception was followed by an informal smoker at the Faculty Club on the Columbia campus.

Session of Friday, December 28

The Society met at 9.45 o'clock a m, in the west assembly hall of the American Museum of Natural History, Acting President Davis in the chair.

Announcements were made by the chair, by E. O. Hovey for the local committee, and by F. J. H. Merrill for the dinner committee.

The report of the Council was taken up and adopted without alteration.

The report of the Photograph Committee was read, as follows:

SEVENTEENTH ANNUAL REPORT OF THE COMMITTEE ON PHOTOGRAPHS

During the year 1906 there has been but little change in the collection of photographs belonging to the Society. No new views have been obtained, but, through the kindness of the Director of the Geological Survey, about 60 old prints have been replaced by new ones, which are printed in a superior manner and mounted on muslin. By this means the bulk of the collection has been considerably diminished.

The photographs are now stored in glass cases in my office, in the building of the Geological Survey, at Washington convenient for reference. Several members of the Society have obtained prints for use in reports and text-books and it is believed that there ought to be a very much wider use of the photographs for this purpose. It is expected that during the coming year a large number of new photographs will be added to the collection, selected from the numerous views which have been taken by members of the Geological Survey during the past few years. Contributions for the collection are desired, but care should be taken that they are views of general interest and illustrate geologic phenomena rather than scenery. A high technical standard is also requested.

Respectfully submitted.

N. H. Darton,
Committee.

On motion, the report was adopted and the usual appropriation of $15 for the use of the committee was voted.

RESOLUTIONS CONCERNING RETIRING SECRETARY AND TREASURER

John M. Clarke then presented resolutions regarding the Secretary and the Treasurer; which, on motion. were unanimously and most heartily adopted. The resolutions were as follows:

After sixteen years of service as Secretary of the Geological Society of

America, Professor H. L. Fairchild meets with us at this session for the last time in his official capacity.

These years of his service have witnessed the robust and vigorous growth of this Society. To his fidelity, enthusiasm, patience, conservatism, and lofty ideals we must ascribe in very large part the virile and promising condition of this Society today.

The Fellows of the Geological Society of America desire to enter on its permanent records this expression of appreciation of such devoted service and this acknowledgment of and gratitude for so willing a sacrifice on behalf of the progress of geological science in America.

Since 1891 Doctor I. C. White, now retiring from office, has served as Treasurer of this Society. For these sixteen years he has given to the management of its finances the benefit of his clear, practical judgment and his experience, and he has so carefully nursed its slender income that today the treasury of the Society presents a most substantial and very gratifying showing.

The Fellows of the Society desire to record an expression of their appreciation of this watchful, faithful, and profitable service.

On motion, the Society voted that after the reading of the next two papers there should be a division into two sections, in one of which should be read the papers on physical and structural topics and in the other the papers on economic, biographic, and glacial subjects.

The first paper of the day was

GEOLOGIC MAP OF NORTH AMERICA

BY BAILEY WILLIS

Remarks were made to the paper by W. M. Davis and W. H. Hobbs.

The next paper was

THE GEOLOGIC FOLIO

BY WILLIAM HERBERT HOBBS

The paper was discussed by C. D. Walcott.

The following paper was then read by title:

GEOLOGICAL MAP OF MASSACHUSETTS AND RHODE ISLAND

BY B. K. EMERSON

Although the paper was read by title only, the map was displayed at the meeting.

At this point in the program the Society separated into two sections. The first section, that including papers on physical and structural geology, remained in the west assembly hall and listened first to the paper,

CAVE SANDSTONE DEPOSITS OF THE SOUTHERN OZARKS

BY A. H. PURDUE

This paper has been published as pages 251–256 of this volume. The paper was discussed by A. W. Grabau, Bailey Willis, H. C. Hovey, W. M. Davis, M. L. Fuller, T. C. Hopkins, and the author.

Former President H. S. Williams was called to the chair.

The next paper was

CURRENT METHODS OF OBSERVING VOLCANIC ERUPTIONS

BY T. A. JAGGAR, JUNIOR

Remarks were made by H. F. Reid and Bailey Willis.

RESOLUTION CONCERNING INVESTIGATION OF VOLCANOES

The following resolution was then presented by T. A. Jaggar, Jr.:

WHEREAS Canada, the United States, and Mexico possess, in the Cordilleran belt, Alaska, the Philippines, the Hawaiian islands, Porto Rico, the Windward islands, and the Canal zone, a wide field for the investigation of earth movement and active volcanoes; and

WHEREAS geologic science needs permanent records, made in the field, of physical phenomena accompanying earthquakes and eruptions, both before and after the event; and

WHEREAS such records have direct bearing on prediction and on protection of life and property; therefore be it

Resolved, That the Geological Society of America strongly recommends to the several governments and to private enterprise the establishment of permanent volcano and earthquake observatories.

The resolution was referred to the Council for report the next day.

Acting President Davis resumed the chair.

The following paper was then presented:

EXPERIMENTS ILLUSTRATING EROSION AND SEDIMENTATION

BY T. A. JAGGAR, JR.

The last paper of the morning session of this section was

CHARACTERISTICS OF VARIOUS TYPES OF CONGLOMERATES

BY G. R. MANSFIELD*

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* Introduced by W. M. Davis.

This paper was discussed by A. W. Grabau, J. Barrell, W. G. Miller, C. W. Brown, and W. M. Davis. The paper has been published in *The Journal of Geology*, volume xv, pages 550–555, September-October, 1907.

The second section met in the small assembly hall, on the third floor of the Museum building, and organized by electing A. P. Coleman chairman and H. M. Ami secretary.

The first paper read was

THE COBALT, ONTARIO, SILVER AREA

BY WILLET G. MILLER

The paper was discussed by S. F. Emmons, R. Bell, E. R. Buckley, and the author.

The next paper was read by title:

VIRGINIA BARITE DEPOSITS

BY THOMAS LEONARD WATSON

The following paper was read:

GEOLOGY OF SANTA BARBARA AND SUMMERLAND OIL FIELDS, CALIFORNIA

BY RALPH ARNOLD

Remarks were made by R. Bell, G. C. Martin, and the author.

The next paper read was

MEMORIAL OF A. R. C. SELWYN

BY H. M. AMI

[*Abstract*]

Selwyn was a geologist who attained distinction for his work in Great Britain, Australia, and British America. In 1845 he began his researches in England and Wales, in 1853 was appointed director of the Geological Survey of Victoria, Australia, and in 1869 succeeded Sir William E. Logan as director of the Geological Survey of Canada. Volcanic rocks and their relations to the earlier sedimentary formations formed the principal object of his energies in these three portions of the Empire, while he did much to emphasize the economic relations of these rocks to pure geological investigations. In Canada Selwyn wrought from December, 1869, to January, 1895, a period of twenty-five years. He traversed the continent before the transcontinental lines of railways were built, and directed the efforts of his staff to many of the portions of Canada whose resources to-day prove of such remarkable value. He received many distinctions at home and abroad.

Both sections adjourned for luncheon together, at the Manhattan Square hotel, and reconvened as a body at 2.30 o'clock p m.

Acting President Davis occupied the chair and gave the floor to W. G. Tight, who presented to the Society a most cordial invitation to hold its next meeting at Albuquerque, New Mexico. Two other equally cordial invitations were before the Council, but the Society by a large majority expressed its approval of holding such a western meeting and recommended the invitation to the Council for favorable consideration.

The Acting President then read the posthumous presidential address of Professor Israel C. Russell. This address is entitled

CONCENTRATION AS A GEOLOGICAL PRINCIPLE

and has been printed as pages 1–28 of this volume.

The Society then divided into two sections, as before, and proceeded with the reading of papers.

In the Physical and Structural section, under the chairmanship of the Acting President, the first paper read was

DOME STRUCTURE IN CONGLOMERATE

BY RALPH ARNOLD

[*Abstract*]

In Eagle Rock valley, near Pasadena, California, are several dome-shaped structures, developed in lower Miocene conglomerate, of water-worn plutonic rocks. The largest dome is Eagle rock, about 80 feet high. This, in a general way, resembles the granite domes of the Sierras, but is much smaller. Scales, or plates, of the rock from a fraction of an inch to as much as 8 feet in thickness cover much of the sloping dome surface, while large quantities of broken scales from detrital heaps at the base of the rock. Not far distant from Eagle rock are other examples of the dome surface. In all cases the scales are not found on slopes of less than 30 or 40 degrees nor on the exposed southern faces or other portions of the rocks which are kept practically dry. The cracks under the scales always penetrate upward approximately parallel to the outer surface. The incipient cracks are closely followed by a zone of weathering which shows lamination parallel to the crack. Iron and other stains emanate from the cracks.

Two general theories have been advanced in explanation of such peculiar structure, all, heretofore, however, based upon observations of the development of domes in granite. According to one theory, the separation of the granite into curved plates is an original structure, antedating the sculpture of the country and determining the peculiarities of form. According to the other theory, the structure originated subsequently to the form, and was caused by some reaction from the surface. The conclusions reached by the writer regarding the origin of the conglomerate domes are as follows:

In the first place, they are locally hardened portions (gigantic concretions,

if you please) of a practically homogeneous conglomerate. After the ordinary process of erosion uncovers a sufficient surface of the indurated rock, the dome structures are formed by a successive scaling off of blocks, through the development of cracks approximately parallel to the steeply sloping surfaces. These cracks are probably due to expansive force developed by chemical reactions (weathering) produced largely by moisture, the moisture passing upward by capillarity through the incipient cracks caused by expansion, and thus advancing the process. The cracks originate in positions advantageous to the accumulation or retention of the moisture producing the weathering, such, for instance, as that occupied by the detrital material at the base of the slope or in the angle between overhanging blocks and the new dome surface. The direction of the cracks is determined by the configuration of the rock surface, being approximately parallel to it, the departures from strict parallelism being of such a nature as to omit angles and other features of irregularity. This parallelism to the surface is due to the expansive force acting along lines of least resistance, which in this case are practically normal to the outer rock surface. The slope of the surface is the governing function in the removal of the scales because the component of gravity tending to dislodge the separated scales is greater on steep slopes than on low, while the component of the same force tending to counteract the expansion due to weathering is correspondingly less on steep slopes, becoming greater as the angle of declivity lessens.

The paper was published in full in *The Journal of Geology*, volume xv, pages 560–570, September-October, 1907.

The next two papers were read without intermission and were discussed together. They were

RELATIONS BETWEEN CLIMATE AND TERRESTRIAL DEPOSITS

BY JOSEPH BARRELL

[*Abstract*]*

Contents

General Introduction

The environment of the lands may be classified into three fundamental and independent factors—the relations to the surrounding seas, the topography which forms their surfaces, and the climates which envelop them—each of major importance in controlling the character of the lands. . . . The third great problem of terrestrial environment, the succession of ancient climates, lags behind the other two in development, but is no less important in a com-

* To be published in full in Journal of Geology, vol. xvi, 1908, beginning with no. 2.

plete understanding of the history of the earth and its inhabitants. This backwardness is doubtless due to the intangible nature of climate and the lack of direct record of its geologic changes. When it is considered, however, how fundamental are the relations of continental deposits to the climates in which they are formed, it is seen that the record of geologic climates, while indirect and to a considerable extent awaiting interpretation, is nevertheless in existence. This is exclusive of the significance of salt and gypsum deposits on the one hand or of glacial deposits on the other, which are of course universally recognized, but these are the marks of climatic extremes.

The causes of climatic variations as distinct from the stratigraphic record of climates have in recent years received a large amount of attention, with the result that a considerable body of knowledge has taken the place of previous speculation. But what are the geologic records of that great variety of climates which, excluding the desert belts of the world, reach at present from the equator to the frigid zones? They may be most favorably studied in ancient continental deposits, since these are free from the contributory record of the sea; and, as it is the average climates which it is sought to investigate, it is especially in ancient fluviatile deposits of continental nature rather than in deposits of desert or glacial origin that the record is to be found. In such river deposits each stratum represents an old land surface, the seat of abundant animal and vegetable life, sealed and protected by the laying down of the succeeding strata instead of destroyed by erosion, the dominant process acting on the land surface. In such deposits the evidence most usually studied is that from the teeth and feet of animal fossils, or the nature of vegetable remains. But many continental deposits are without fossils and many groups of organisms show a wide climatic range; so that it is very desirable that other features constantly present, such as the chemical, textural, and structural characteristics of the strata, should be available for the climatic interpretation. The significance of such features has of course not entirely escaped attention; the presence of red in shales or sandstones is sometimes cited as evidence of derivation from a deeply decayed and highly oxidized regolith, or the existence of a conglomerate whose pebbles are of vein quartz as evidence of the thorough decomposition of an ancient soil; but such expressions have been made without a preliminary investigation into all the possible modes of origin, and it will be found that other interpretations are also possible.

The problem, then, in the present paper is to separate the influence of the topographic from the climatic factors in the making of terrestrial sediments. In seeking for data to draw the lines more closely, it is found that the relations of climate to the nature of the land waste and river sediments has attracted the attention of relatively few explorers and scientists. Such exceptions must, however, be noted as Blanford and Oldham, Walther, Hilgard, Merrill, Russell, Davis, and Huntington. These men, with a few others, have largely supplied the data which make the discussion possible.

The first part, dealing with the relations of climate to erosion, is necessarily largely physiographic, and, in the case of material which is carried long distances by rivers, these relations are of less final influence than the conditions under which the sediments are deposited and those of the preceding transportation. The purpose of the whole paper is, however, not physiographic, but

stratigraphic. For this reason it is the relation of physiography to erosion and consequent supply of sediments which is dwelt upon rather than the discussion of the land forms as an end of investigation. Owing to this somewhat unusual use of physiography as well as the desire to make the discussion more complete for students in other branches of geology, it is necessary to go over some ground which is familiar to physiographers. Even from a physiographical standpoint, however, it is thought that a brief general discussion of all the climatic factors influencing erosion is not without its value, since it is found to suggest some new points of view upon several old problems. For the elaboration of the second and third parts, those upon the relations of climate to fluviatile deposition and the preceding transportation, sufficient reason is found in the existence of the diverse views held by many working geologists upon the significance of various stratigraphic characters, and, furthermore, in the general conclusion of the present paper, that climate is a factor comparable to disturbances of the crust or movements of the shoreline in determining the nature and the variations in the stratified rocks of continental or offshore origin, thus playing a part of large, though but little appreciated, importance in the making of the stratigraphic record.

The investigation was instituted to see to what extent profound climatic variations, complicated doubtless with some tectonic movements, could account for the great contrasts in the Lower and Upper Carboniferous formations of eastern Pennsylvania—formations which had been found by the writer from observations in the field to be continental in nature, and therefore their contrasted features not to be attributed to changes in the relations of land and sea.

An abstract of the body of the paper is as follows:

Part I. Relation of Sediments to Regions of Erosion

Observations of the nature of river sediment show that it is only in local deposits that the character is markedly due to the kind of rocks undergoing erosion, so that in regions where the sediment has no relation to the adjacent formations but little difficulty will be found in allowing for the more or less unknown lithological nature of the source.

The interrelations of topography and climate to erosion are more complicated, but it is shown from present instances that even where land relief leads to vigorous erosion the influence of arid or humid climates is able to make itself felt in the ratio of coarse to fine material and the freshness or degree of decomposition of the fine. In the mature stage of the topographic cycle these differences become accentuated. The influence of old topography is of less importance, since under such conditions fluviatile continental deposits are reduced to a minimum. Between the climatic extremes, however, the results, as are well known, are still conspicuous, leached clays being the mark of rainy and loess and dune sand of arid climates.

Under the relations of temperature to erosion, the influences of vegetation, of frost action, of snow action, and of insolation are discussed. It is noted, as Chamberlin and Salisbury have pointed out, that *increased cold* tends to weaken the power which vegetation possesses in producing decay but preventing erosion. *Increased frost action* is found to greatly increase the rate of

disintegration in young or mature topography without correspondingly increasing the powers of waste-removal. The Gila conglomerate of Arizona is discussed as an example of a great conglomerate formation resulting primarily from a climatic change in which the ratio of erosion to transportation had been increased through increased frost action at times of glaciation in other regions. *Increased snowfall* works in an opposite direction, by protecting the surface from disintegration and promoting transportation.

Under the effects of climatic changes resulting in an *increase of temperature*, it is pointed out that in regions of topographic relief insolation is a weaker force than frost action. In all geologic times, irrespective of climatic variations, it has worked most strongly in the torrid and has been practically absent from the polar zones. In intensity it must have varied considerably, owing largely to geographic as well as possibly to solar conditions. In regions of humid climate rock decay takes the place of insolation and also operates most strongly in the torrid zone; but on account of the mat of vegetation it is not known if erosion is weaker or more rapid than in a temperate climate.

In conclusion, it is pointed out that an examination of the *matrix* of fluviatile conglomerates is of importance for separating the climatic from the topographic conditions of origin, while the *simultaneous development* of conglomerates within many hydrographic basins, as Davis has shown, may point to a climatic as against a tectonic origin. Finally the relative rates of erosion under various climates are discussed and it is concluded that the development of plains of marine denudation depends largely on the climatic factor, taking place most readily in an arid climate. As a result of the discussion of the first part, it is concluded that climatic variation is a major factor, comparing with subordinate tectonic movements, in governing both the kind and quantity of the material supplied to the rivers.

Part II. Relation of Sediments to Regions of Deposition

In the second part, the influence of topography is first considered, the piedmont slopes being notably better drained than deltas and only covered with carbonaceous deposits in a cool and rainy climate. Over the delta there is a progressive flattening of the grade with the production of swamp areas, to some extent even in desert climates. A number of factors independent of the climate, such as the building of two confluent deltas or a slowly rising water level, tend to increase the area of swamp; but in desert climates there is a close association of the swamp deposits with sharply contrasted evaporation and æolian products. Under all climates the amount of swamp area reaches a maximum on the seaward margin of the delta. Following this preliminary discussion, the effects of five kinds of climates are considered: constantly rainy, arctic, intermittently rainy, semiarid, and arid. Each impresses well marked distinctions upon the flood-plain deposits. The constantly rainy gives rise to carbonaceous and well leached clays and sands, besides beds of peat; the arctic climate differs in the less leached clays, containing especially more potash; in intermittently rainy climates the carbonaceous deposits of the flood-plains are local, the materials are oxidized during seasons of dryness, the clays are slightly calcareous, and fossils are apt to be scanty. It is concluded that such deposits occur to an unappreciated extent in

the geologic record and are apt to be classed with marginal marine formations on account of their lack of definite characteristics. In semiarid climates the deposits show not only a higher oxidation, but the clays contain more potash and are markedly calcareous. As swamp deposits diminish, mud-cracked strata increase and may become noteworthy. Under arid climates potash-bearing and calcareous clays and mud-cracked strata become more prominent; æolian and especially evaporation deposits of gypsum and salt also occur; oxidation of the delta materials is almost universal, with the result that dark or variegated shales are nearly absent. A discussion of the climatic significance of color follows, and it is concluded that red is the common color of consolidated fluviatile deposits which were subjected at the time of their accumulation to seasons of subaerial oxidation, and that red shales and sandstones may therefore arise from either the yellow or red alluvium of intermittently rainy, semiarid, or arid climates. In conclusion it is pointed out that while the varying powers of erosion and transportation are delicate stratigraphic indicators of *climatic fluctuations*, the chemical and organic control accompanying the deposition are the more secure indicators of the *average climatic conditions.*

Part III. Relations of Climate to fluviatile Transportation

This subject is considered last, since except in connection with the conditions of erosion and deposition the climatic relations of transportation are not conspicuous. Laboratory experiments and observations of river action lead to the induction that one of the reasons why rivers carry coarse material such short distances is because of the mechanical weakness of all but quartz and quartzite pebbles and the consequent loading up of the current with finer material. The slope of a graded river is in delicate adjustment between the amount of water and the amount of the load, and consequently every change in these factors throws it out of equilibrium. As a result, sometimes cutting and sometimes depositing is in excess throughout the middle portion of its course. In the case of long rivers flowing from regions in topographic youth or maturity, as those flowing east from the Andes and Rockies, a very great difference in grade exists, according as the river course lies in a semiarid or rainy climate. Under semiarid climates piedmont slopes may be built up to a thickness of a thousand feet or more, and in a climatic variation to one of pluvial nature this may be rapidly carried away, and, since it consists largely of sand and gravel, a great sand or conglomerate formation will be spread over the delta plain. The dissection in the early Pleistocene or latest Tertiary of the high plains fronting the Rocky mountains is cited as an instance. On the other hand, upon a change of climate from humid to semiarid, another sand and conglomerate formation will be laid down close to the mountains as a piedmont slope, building up the river channel to a steeper grade. From this it is concluded that the region of deposit of river gravels and its shiftings is of great climatic significance.

Summary and Conclusion

Summing up the preceding discussion, it is to be concluded that conglomerate and sandstone formations intercalated between others of different nature may be due to three distinct causes:

First. Marine conglomerates and sandstones, due to marine planation and transportation, enabled to reach wide horizontal extent over shallow seas through crustal movements shifting the zone of wave and current action.

Second. Tectonic, conglomerates and sandstones, due to subaerial erosion, owing to a steepening of the river slopes, either from mountain making, crustal warping, or subsidence of the ocean level.

Third. Climatic conglomerates and sandstones, due to climatic change, without necessarily any new and accompanying crustal movement, producing a shifting of the region of accumulation of gravel or sand and a resulting contrast in coarseness, in color, and in chemical composition with the underlying and overlying formations. It is by means of the associated features that climatic conglomerates are to be distinguished from those of tectonic origin. For these two to be sharply separable in nature, the climate must remain stable during an epoch of crustal movement and, *vice versa*, earth movements must be supposed quiescent during a time of climatic change. As tectonic and climatic movements may be intermixed, there may often be a dual cause of conglomeratic formations.

The establishing of a class of climatic conglomerates involves the conception of the shifting location of deposits (*in space*) during an epoch of crustal quiet as being of the same geologic importance as the varying pulses of erosion (*through time*) due to tectonic movements.

In conclusion, it is seen that by means of conglomerate or sandstone formations the important changes are recorded in each of the three fundamental environments of the lands, namely, the relations to the surrounding seas, the topography which forms their surfaces, and the climates which envelop them.

ORIGIN AND SIGNIFICANCE OF THE MAUCH CHUNK SHALE

BY JOSEPH BARRELL

This paper is printed as pages 449–476 of this volume.

The two foregoing papers were discussed by D. White, B. Willis, E. Huntington, A. W. Grabau, W. M. Davis, and the author.

The next paper was

RIVER SEDIMENT AS A FACTOR IN APPLIED GEOLOGY

BY W J MC GEE

The last paper of the afternoon in this section was

ORIGIN OF OCEAN BASINS IN THE LIGHT OF THE NEW SEISMOLOGY

BY WILLIAM HERBERT HOBBS

This paper forms pages 233–250 of this volume.

The second section met with George P. Merrill in the chair and H. M. Ami acting as secretary.

The first paper on the program was read by title:

PERSONAL REMINISCENCES OF SIR WILLIAM E. LOGAN

BY ROBERT BELL

[*Abstract*]

In his day Logan was one of the most prominent geologists, not only of America, but of the world, being well known in Europe. In the present strenuous times, new men come rapidly upon the stage, and although this great geologist has been dead only about thirty years, his name is not familiar to the younger generation. While the above mentioned paper deals largely with instructive personal incidents and amusing anecdotes, it serves to illustrate the evolution of the geology of eastern North America and the growth of the Geological Survey of Canada.

Logan having pursued scrupulously honorable methods in scientific matters as in everything else, his example was an inspiration to all who were associated with him. His desire to give credit to his assistants for their share in the work secured for him enthusiastic followers, among whom were Murray, Hunt, Billings, and others. His painstaking methods and wonderful powers of observation and reasoning show, in the light of our present knowledge, his marvelous insight as to the relations of the various series of rocks to one another, and his classification and nomenclature of sixty-odd years ago, when geology itself was in its infancy, were adopted two years ago as the best possible, by the International Committee on the Lake Superior rocks.

Logan's life and times are so full of interest to all geologists that it is believed this short sketch at first hand by one who was so intimately associated with him is worth preserving.

This was followed by

A LOWER HURONIAN ICE AGE

BY A. P. COLEMAN

The discussion which followed was participated in by W. G. Miller, R. D. Salisbury, A. C. Lane, R. Bell, F. G. Clapp, and the author. The paper has been published in full in the American Journal of Science, volume xxiii, 1907, pages 187–192.

The next two papers were read by title:

GLACIATION OF MANHATTAN ISLAND, NEW YORK

BY ALEXIS A. JULIEN

GLACIAL EROSION IN THE NORTHFIORD

BY MARK S. W. JEFFERSON

This paper has been printed as pages 413–426 of this volume.

The next paper read was

RECENT CHANGES IN THE GLACIERS OF GLACIER BAY, ALASKA

BY F. E. AND C. W. WRIGHT

The paper was discussed by W. Blake (a visitor), H. F. Reid, F. P. Gulliver, G. F. Wright, and F. E. Wright.

The last paper of the session was

RECENT CHANGES IN THE MALASPINA AND OTHER GLACIERS OF THE YAKUTAT BAY REGION, ALASKA

BY RALPH S. TARR

Remarks were made by T. A. Jaggar, Jr., H. F. Reid, A. H. Brooks, and the author. The paper forms pages 257–286 of this volume.

The evening was devoted to the annual dinner of the Society, which was the largest that has been held, 138 Fellows and guests participating. W. M. Davis presided.

Session of Saturday, December 29

The Society met in general session at 9.45 o'clock a m, with Acting President Davis in the chair.

REPORT OF THE AUDITING COMMITTEE

The Auditing Committee reported that the accounts of the Treasurer had been found correctly cast and properly vouched.

On motion, the report was accepted and ordered placed on file.

The Secretary reported that the Council had voted that the next meeting of the Society be held at Albuquerque, New Mexico, December 30, 1907, to January 1, 1908, and that the resolutions offered by T. A. Jaggar, Jr., had been referred to a committee, consisting of T. A. Jaggar, Jr., J. F. Kemp, and E. O. Hovey, for consideration and report at the next annual meeting of the Society.

After some other announcements the Society divided into two sections, as before, and the scientific program was taken up. The Physical and Structural section remained in the west assembly hall, with Acting President Davis in the chair.

The first paper read was

HYPOTHESIS OF CONTINENTAL STRUCTURE

BY BAILEY WILLIS

Discussion was offered by C. Schuchert, A. Heilprin, B. K. Emerson, F. E. Wright, and the author. The paper appears as pages 389–412 of this volume.

The next paper was read by title:

THE LIMELESS OCEAN OF PRE-CAMBRIAN TIME

BY REGINALD A. DALY

This paper has been published in full in the American Journal of Science, volume xxiii, 1907, pages 93–115.

The following paper was then read:

PERMO-CARBONIFEROUS CLIMATIC CHANGES IN SOUTH AMERICA

BY DAVID WHITE

[*Abstract*]

The fossil plants collected by the Coal Commission of Brazil not only confirm the existence of the Lower Gondwana flora in Brazil, but they offer striking evidence of climatic changes. At the same time they afford new data relating to Permo-Carboniferous southern land connections and the distribution of Permian glaciation.

The stratigraphy of the Brazilian coal measures is admirably worked out by Dr I. C. White, late chief of the commission, in his paper "Coal Measures and higher beds of South Brazil," which he summarized at this meeting of the Society. For the descriptive and systematic discussions of the fossil plants, embracing 140 species, the reader is referred to the official Brazilian report.*

The fossil plants in the series immediately above the basal conglomerates, which repose unconformably on the ancient eruptives, comprise a typical Lower Gondwana flora, including its principal and characteristic species as well as genera. This flora is so far identical with that associated with the glacial boulder-bearing sediments in Australia and overlying the glaciated conglomerates in India and South Africa as to leave no room for doubt as to the contemporaneous existence of a similar cold climate in South America. The consequent inference as to glaciation in that continent is lithologically proven according to Doctor White, who confirms the observations and tentative views offered in 1889 by Derby.

The beds 130 meters above the base of the Tubarão series show numerous megaspores apparently of Sigillarian origin. The evidence of the return of representatives of the northern or cosmopolitan flora is more abundant in the region of 175 meters above the base, where we find *Sigillaria brardii*,* *S.*

* Commissao dos Estudos das Minas de Carvao de Pedro do Brasil. Rio de Janeiro, 1907.

australis, *Lepidodendron pedroanum*,* and *Lepidophloios laricinus* again assuming the rôle of coal-makers. Mingled with them are species of Gangamopteris, Glossopteris, and Phyllotheca, of the Gangamopteris flora. It is plain, therefore, that an amelioration of climate sufficient to permit the return of some of the northern types had already taken place; and it is equally evident that the absence of these types during the deposition of the lower beds was due to climatic inhospitality rather than to a marine or other barrier.

The paleobotanical material from the region of the Iraty black shale and the succeeding beds of the Passa Dois series is confined to fossil stems. This is the zone of the *Psaronius brasiliensis* described by Brongniart, and of the *Lycopodiopsis derbyi* and the *Dadoxylon pedroi* respectively described by Renault and Zeiller, as well as of the *Stereosternum tumidum* Cope and *Mesosaurus brasiliensis* McGregor. The Pasa Dois series has also furnished another large Lycopodialean tree, probably belonging to Sigillaria, and two new gymnosperms referred to Dadoxylon. The presence of Psaronius would seem to indicate the return of Pecopterids, presumably of the Cladophleboid group, to the southern Brazilian basins. This indication of further moderation of the climate is corroborated by the woody structure of the fossil trees, in which there are extremely obscure, if any, traces of annual rings, the growth of the trees being apparently uninterrupted by seasonal changes. It is therefore permissible to conclude that at this time a mild and equable climate once more prevailed, so that the surviving elements of the Permian cosmopolitan flora were able freely to migrate and mingle with the survivors of the Gangamopteris flora.

The date of South American glaciation, which on the paleobotanical evidence appears to have been contemporaneous with the Dwyka in South Africa, the Talchir of India, and possibly the later Newcastle ice in Australia, would seem to be at or extremely near the close of the Carboniferous. That the severe cold was of short duration is shown by the early return of some of the exiled northern Permo-Carboniferous plants. The fact that the postglacial moderation of the climate occurred some time before the extinction of Lepidophloios and Lepidodendron conclusively shows that the climatic refrigeration could not have occurred later than the very early Permian. It is interesting to note that the types first to return, and therefore presumably the hardiest, belong to the Lycopods.

The distribution in India, Australia, South Africa, and South America of a terrestrial flora of varied elements like the older Gondwana flora necessitates a distribution of the land masses in such a way as to permit land plant migration with absolute freedom between these regions. The testimony of vertebrates and plants is mutually corroborative on this point. The author inclines to recognize the important agency of an Antarctic land mass or continent, of which southern South America or South Africa may have been mere lobes, in facilitating this free intermigration.

The abstraction of carbon dioxide from air and sea and the storage of the same in the coals, carbonaceous shales, and limestones of the Upper Carboniferous has never been equaled in any other period of geological history.

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* The employment of capital initials for names of species directly derived from names of persons is not permitted by the rules for printing early adopted by this Society.

The hypothesis of Arrhenius and Chamberlin would therefore appear to find circumstantial support in the occurrence of glaciation at the time of the post-Pennsylvanian uplift. If the efficiency of CO_2 as a climatic factor be admitted, not only may the occurrence of refrigeration itself be explained, but perhaps the singular geographical distribution of the ice action as well. The latter would appear to have been the result of complicated influences, very important among which would be the great exaggeration of temperature differences attending differences in altitude in the atmospheric column were there a depletion of the CO_2 of that column. The temperature gradient would be very much steepened and the frost line brought down nearer to sealevel. To this fact, which does not appear to have received due consideration at the hands of geologists, in connection with the probable great size and considerable height of the older Gondwana land masses, as shown by the great thickness of coarse sediments and the great size of the continental basins, is, in the writer's opinion, chiefly due the extension of the Permian glaciation within the tropics.

The next paper was

COAL MEASURES AND HIGHER BEDS OF SOUTH BRAZIL

BY I. C. WHITE

The next paper was read by title:

NORMAL PRESSURE FAULTING IN THE ALLEGHENY PLATEAUS

BY GEO. H. ASHLEY

The following two papers were read without intermission:

CONDITIONS OF CIRCULATION AT THE SEA MILLS OF CEPHALONIA

BY M. L. FULLER

This paper has been printed as pages 221–232 of this volume.

Mr Fuller's paper was discussed by J. F. Kemp and W. M. Davis.

CONTROLLING FACTORS OF ARTESIAN FLOWS

BY MYRON L. FULLER

[*Abstract*]*

Contents

* The full paper is in press as a bulletin of the United States Geological Survey.

Introduction

It is now more than twenty years since the publication of the admirable paper by Professor T. C. Chamberlin on the "Requisite and qualifying conditions of artesian wells,"† during which period it has remained the standard in this country. It deals, however, almost entirely with the porous bedded rocks, such as sandstones, taking little account of the drift or limestones, and practically none at all of the crystalline rocks. Late investigations, especially in the East, and the growing demand for ground water for industrial and public purposes or for summer resort supplies have led to a very extensive development of wells in each of the classes of material mentioned, and have shown their great economic as well as scientific importance, emphasizing the need of a reexamination into the requisites of artesian flow and a discussion of their controlling and modifying factors.

In view of the number of different ways in which the term artesian has been used in the past, it will not be out of place to state that in the present paper the term is applied in the sense adopted by the United States Geological Survey after consultation with leading geologists of the country, namely, to designate the hydrostatic principle by which confined waters tend to rise in virtue of the pressure of the overlying water column, irrespective of whether or not this pressure is sufficient to lift the water to the surface and produce a flow.*

Artesian flows may be said to depend upon the nature of the reservoirs, the conditions of confinement, and the sources of the water. An enumeration of the factors are given below.

Underground Water Reservoirs

By an underground water reservoir is meant the opening or system of openings within the rocks in which the water is contained. The more important types may be summarized as follows:

Types of Water Reservoirs

I. Original forms.
   1. Original pores.

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† Fifth Annual Report U. S. Geological Survey, 1885, pp. 125-173.

* M. L. Fuller: Significance of the term "Artesian." Water supply and irrigation paper no. 160, 1906, pp. 9-15.

2. Lamination planes.
3. Bedding planes.
4. Vesicles (in igneous rocks only).

II. Secondary forms.
1. Secondary pores.
   A. Pores resulting from leaching and solution.
   B. Pores resulting from recrystallization.
2. Solution openings.
   A. Isolated cavities.
   B. Tubular channels.
   C. Sheet openings.
3. Mechanical eroded reservoirs.
   A. Tubular channels.
   B. Pocket openings.
   C. Sheet openings.
4. Fracture openings.
   A. Irregular openings.
      a. Desiccation cracks.
      b. Contraction fissures.
      c. Tortion fractures.
      d. Shearing breaks.
      e. Vibration fractures.
      f. Explosion ruptures.
   B. Joints.
      a. Vertical joints.
      b. Horizontal joints.
      c. Parallel joints.
      d. Intersecting joints.
      e. Joint breccias.
   C. Faults.
      a. Single fault planes.
      b. Parallel fault planes.
      c. Irregular faults.
      d. Intersecting faults.
      e. Fault breccias.
5. Vein contacts.
6. Igneous contacts.
7. Shearing planes.
8. Cleavage planes.
9. Foliation and schistosity planes.

Most of the forms enumerated are not limited to any particular class of rock, but may be found in the stratified, metamorphic, and igneous types. The vesicles of igneous rocks, however, have no exact counterpart in stratified rocks, although the pores containing included water of sedimentation approach them in nature. Solution channels are likewise usually, although not necessarily, found only in sedimentary rocks, foliation and schistosity are mainly features of igneous or metamorphic rocks, while lamination, as the term is here used, is a feature of stratified rocks.

Sources of Underground Water

The probable source of underground waters has been widely discussed, and while every one would doubtless agree that by far the greater part is derived from rainfall, there is a considerable variation of opinion as to the relative importance of the other sources, and especially as to the part played by the sea and aqueous magmatic emanations. The common sources of underground waters are as follows:

List of Sources of Underground Water

I. Atmosphere.
  A. Direct.
    a. Precipitation.
    b. Condensation.
  B. Indirect.
    a. Lakes.
    b. Streams.
II. Hydrosphere, or ocean.
  A. Recently or contemporaneously absorbed waters.
  B. Originally included sea water.
III. Lithosphere, or crust.
  A. Primary waters.
    Chemically excluded waters.
  B. Secondary waters.
    Physically excluded waters.
IV. Centrosphere, or interior.
  A. Directly excluded waters.
  B. Indirectly excluded magmatic waters.

Confining Agents

In the discussion of the confining agents in artesian systems the materials are divided for convenience into bedded and jointed rocks. In the usual discussion the impervious bed is ordinarily the only agent recognized, but the extensive fieldwork which has been conducted by a considerable body of workers for the last three years has brought to light some new agents and emphasized the importance of other seldom mentioned factors.

List of Confining Agents

I. Bedded rocks.
  A. Upper confining agents.
    1. Impervious beds.
    2. Stratification.
    3. Friction.
    4. Mineral crusts.
    5. Frost zones.

6. Confined air and gas.
7. Fresh water.
8. Salt water.

B. Lower confining agents.
1. Impervious beds.
2. Stratification.
3. Friction.
4. Mineral crusts.
5. Frost zones.
6. Confined air and gas.
7. Fresh water.
8. Salt water.
9. Cementation.
10. Heat.
11. Pressure.

II. Jointed and fractured rocks.

A. Upper confining agents.
1. Impervious hanging wall.
2. Impervious surface coverings.
3. Frost fillings.
4. Vein fillings.
5. Weathering products.
6. Converging walls.
7. Interrupted joints.
8. Sea water.

B. Lower confining agents.
1. Impervious footwalls.
2. Vein fillings and cementation.
3. Converging walls.
4. Interrupted joints.
5. Fresh water.
6. Sea water.
7. Heat.
8. Pressure.

Nature of Artesian Circulation

Artesian circulation takes place by virtue of the variations of pressure to which the water is subjected in different parts of its reservoirs. By definition of the artesian principle, all but hydrostatic pressure is excluded as a determining cause of circulation. There are, nevertheless, a number of modifying agencies which in cases exert a powerful influence on the water-head and movements. The more important of the controlling factors may be summarized as follows:

Factors in Artesian Circulation

Primary factors.
Gravity (hydrostatic pressure).

- Modifying factors.
  - Factors affecting pressure.
    - Barometric variations.
    - Temperature variations.
    - Density of waters.
      - Variations due to temperature.
      - Variations due to dissolved salts.
    - Height of adjacent water levels.
      - Water table.
      - Neighboring water bodies and supply.
      - Tides.
      - Winds.
    - Rock pressure.
  - Factors affecting movement.
    - Porosity.
    - Size of grain openings.
    - Temperature.

Requisites of Artesian Flows

Having outlined the more important conditions bearing on the occurrence and movements of underground waters, the controlling factors of artesian flow may be considered. In doing this it is necessary to point out certain objections to some of the commonly postulated requisites.

Objections to Common Requisites

CHAMBERLIN'S REQUISITE CONDITIONS OF ARTESIAN FLOWS

Since the appearance in 1885 of the paper of T. C. Chamberlin on the "Requisite and qualifying conditions of artesian wells," a single set of requisites has, with few exceptions, been followed by writers of underground water papers. These in brief are: (1) A pervious stratum, to permit the entrance and the passage of water; (2) a water-tight bed below, to prevent the escape of water downward; (3) a like impervious bed above, to prevent the escape upward, for the water, being under pressure from the fountain head, would otherwise find relief in that direction; (4) an inclination of these beds, so that the edge at which the waters enter will be higher than the surface at the well; (5) a suitable exposure of the edge of the porous stratum, so that it may take in a sufficient supply of water; (6) an adequate rainfall, to furnish this supply; and (7) an absence of any escape for the water at a lower level than the surface at the well.

There is one very serious objection to the requisites outlined above, namely, they apply only to a single class of flows from stratified rocks, neglecting not only flows from other varieties of rock, but even other types of flow from the same rocks. There are, moreover, many exceptions to the postulated requisites, which, taken in connection with the limitations mentioned, make new and more comprehensive definitions desirable. Some of the objections to the requisites are mentioned below.

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* Fifth Annual Report U. S. Geological Survey, pp. 125-173.

PERVIOUS STRATUM

A pervious stratum, although a common form of reservoir, is seldom essential to artesian flows. In addition to the porous stratum postulated by the first requisite, flows may be obtained from lamination, bedding, cleavage, and shearing planes, from solution passages and mechanically eroded reservoirs, from vesicular zones in igneous rocks, from irregular, joint, and fault fractures, and from vein and igneous contacts. Metamorphic and igneous as well as stratified rocks not only may, but actually do, yield flows in a large number of instances; in many others the water falls only a few feet short of the surface, while in practically all the wells the waters rise materially when encountered—that is, are truly artesian.

With the exception of the vesicular lavas, the sources of water mentioned are not in the nature of beds, but are in the form of actual openings—a type of passage not recognized among the older requisites.

IMPERVIOUS BED BELOW

From the nature of the passages enumerated above and given in more detail in the list on page 628 it is apparent that the second requisite—the impervious underlying stratum—loses much of its force. Such impervious beds are an adjunct to many flows in stratified rocks, but numerous other agents may serve the same purpose. In bedded rocks the following may be mentioned: Stratification, friction, mineral crusts, frost zones, confined air and gas, fresh or salt water, cementation, heat and pressure. In jointed and fractured rocks impervious footwalls, vein fillings, converging walls, interrupted joints, fresh and salt water, heat and pressure, are the most important.

IMPERVIOUS BED ABOVE

The objections to the postulation of an upper impervious bed are similar to those of the lower confining bed just enumerated. In the case of the bedded rocks the following, in addition to the postulated impervious stratum, may serve as confining agents: Stratification, friction, mineral crusts, frost zones, confined air and gas, fresh water and sea water. In the case of jointed and fractured rocks the more common additional agents are impervious hanging wall, impervious surface coverings, frost and vein fillings, weathering products, converging walls, interrupted joints, and sea water.

INCLINATION OF BEDS

Inclination of the water-bearing bed, while a common factor in artesian flow, is by no means essential. Water appears to penetrate in many cases into lenses of sandstone in rocks like those of the Carboniferous of Pennsylvania through joints and similar openings, and flows are obtained independent of any inclination of the bed affording the water. The same is true in the case of the horizontal beds yielding flows by virtue of the opposition of the stratification planes. Joint and solution passages also afford artesian flows independent of any inclination at the point penetrated.

In both bedded and crystalline rocks the pressure must, of course, be transmitted from connecting passages or other water reservoirs at higher levels, but

the supply itself does not necessarily come from a higher level, since besides the downward moving meteoric water supplies may be furnished by the sea, by waters chemically or physically excluded from the crust, or by direct or magmatic exclusion from the centrosphere.

OUTCROP OF POROUS STRATUM

The postulated suitable exposure of the edge of the porous stratum so that it may take in a sufficient supply of water, though a common, is far from an essential factor of artesian flows. Some of the horizontal sandy beds from which the flows are obtained in Long island and Michigan never outcrop, the water penetrating directly downward through the overlying layers. Moreover, throughout extensive areas of the Silurian, Devonian, and Carboniferous rocks in Pennsylvania, West Virginia, and Ohio, in the areas underlain by Cretaceous beds in the Fort Monroe district of Virginia, and the Wilmington region of North Carolina, and in many lesser areas elsewhere, the deep artesian waters represent originally included sea waters and not waters entering through the outcrop. Other sources, including waters chemically or physically excluded from the crust, or by direct or magmatic exclusion from the centrosphere, may furnish artesian supplies independent of the condition of outcrop.

ADEQUATE RAINFALL

From the fact that water may be, and in the case of the salt waters of the Carboniferous and Coastal Plain rocks just described, as well as in the case of magmatic waters actually is, derived over extensive areas from sources other than rainfall, it is clear that the latter should not be included as an absolute requisite.

POINTS OF ESCAPE

There are very few artesian systems in which there is not more or less leakage. In the thicker and more persistent beds the leakage is often sufficient to insure circulation for long distances from the outcrop. Thus, in the Cretaceous beds beneath Charleston, South Carolina, and Savannah, Georgia, fresh water has replaced the salt at least as far as the seacoast, or a distance of over 100 miles from their outcrop. At Fort Monroe, Virginia, and Wilmington, North Carolina, on the other hand, there appears to be but little leakage and the fresh water circulation reaches to a much less distance, only salt water being obtained at the localities mentioned. The absence of leakage appears to have determined the presence of salt waters in the oil-bearing rocks of Pennsylvania and elsewhere.

In order that leakage may prevent flows, it must take place near the point at which the water horizon is tapped. It has been shown many times by Chamberlin and others that its influence is limited. The requisites should therefore postulate the absence of near-by leakage rather than the non-occurrence of leakage.

Essentials of Artesian Flows

The essentials of artesian flows, as recognized by the writer, are as follows:

Essentials of Artesian Flows:

I. An adequate source of water supply.
II. A retaining agent offering more resistance to the passage of water than the well or other opening.
III. An adequate source of pressure.

The first requisite is not made specific as regards source, as artesian waters, as has been pointed out, are not derived from a single but from a variety of sources. In the case of the second requisite the retaining agent may be a stratum, a vein or dike-wall, a joint, fault, or other fracture plane, a water layer, or some one of a variety of other agents. The pressure, while primarily due to differences in level in the different parts of the artesian system, may be transmitted in such a variety of ways and is subject to so many modifying factors that the specification of a definite source is impracticable.

Modifying Factors

It is believed that the three factors of the preceding paragraph are all that can be considered as essential to artesian flows, all other postulated requisites being in reality modifying or accessory rather than essential factors. These secondary factors, which have been enumerated in the preceding pages, may be classed as follows:

Secondary Factors of Artesian Flows

I. Hydrostatic factors (relating to pressure and movement).
  1. Factors mainly affecting pressure.
    a. Barometric.
    b. Temperature.
    c. Density.
    d. Rock pressure.
  2. Factors mainly affecting movement.
    a. Porosity.
    b. Size of pores or openings.
    c. Temperature.
II. Geologic factors (relating to reservoir).
  1. Character of reservoir.
  2. Retaining agents.
  3. Structure of reservoir.
  4. Topographic conditions.
  5. Conditions relating to supply.
    a. Catchment conditions.
    b. Conditions of underground feed.
  6. Conditions of leakage.

No remarks on this paper.

FIGURE 1.—CRATER OF XINANTECATL (NEVADO DE TOLUCA), MEXICO, FROM THE PICO DE FRAILE

The dome in the middle was the last phase of the latest eruption, and is analogous to the dome of mount Pelée, Martinique. It is composed of glassy andesite that welled up from the conduit, but did not form a flow.

FIGURE 2.—VOLCAN DE COLIMA, MEXICO, AUGUST 30, 1906

At left the parasitic cone formed in 1869; at right the lava stream of 1885, surmounted by that of 1903. Courtesy of the Am. Mus. of Nat. Hist. E. O. Hovey, photographer

CRATER OF XINANTECATL AND COLIMA VOLCANO

FIGURE 1.—BREADCRUST BOMB, COLIMA, MEXICO, ERUPTION OF 1903

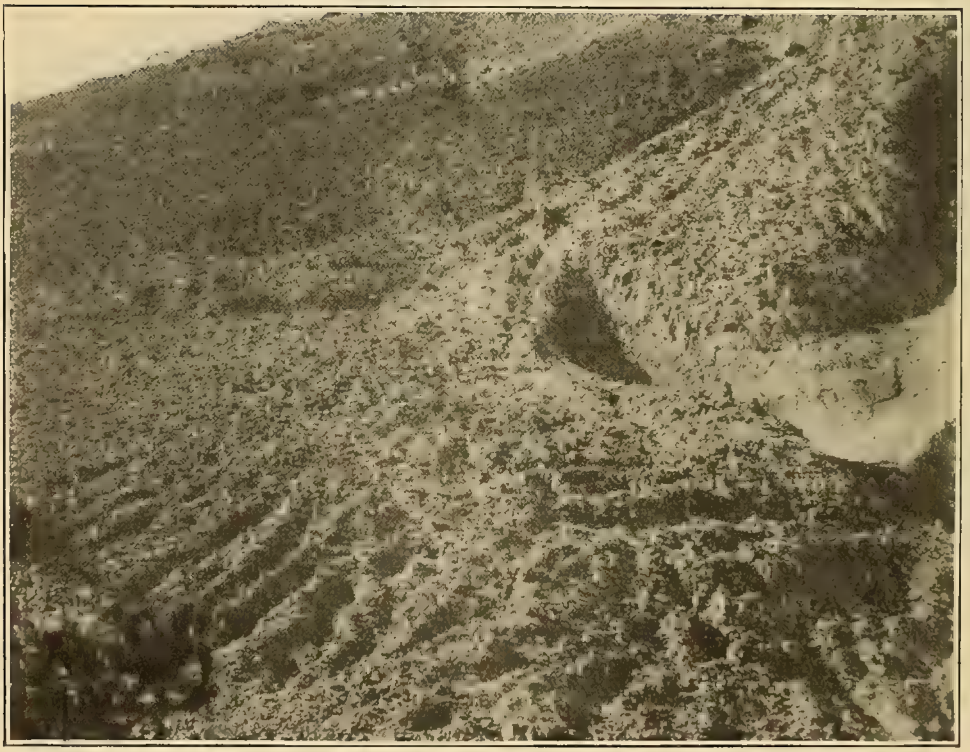

FIGURE 2.—DEEP TRANSVERSE FURROWS OF LAVA FLOW OF 1869, COLIMA, MEXICO

Courtesy of the American Museum of Natural History. E. O. Hovey, photographer

VOLCANIC PHENOMENA COLIMA, MEXICO

The next paper was

VOLCANOES OF COLIMA, TOLUCA, AND POPOCATEPETL

BY EDMUND OTIS HOVEY

[*Abstract*]

The principal object of presenting the paper was to show the Society some photographs of these three volcanoes which were taken upon excursions made in connection with the meeting of the Tenth International Geological Congress in the city of Mexico, in September, 1906.

Toluca is the oldest of the three. A feature of greatest interest in the crater is the dome of vitreous andesite which welled up in the crater as the latest phase of the activity of the volcano and shows a certain resemblance to the new cone of mount Pelée. The volcano of Popocatepetl shows its composite character as a strato-volcano with great clearness in the walls of the crater, and streams of lava have been among the features of the most recent eruptions. The volcano of Colima is still sending up a vigorous column of steam from its central summit crater. From this summit crater there poured out, in the latest eruption (1903), streams of very frothy lava, which present a strange appearance on account of the porous character of the surface blocks. The same feature characterizes the streams of earlier eruptions and has led some observers to the erroneous conclusion that flows of lava have not occurred at the volcano of Colima.

Remarks were made by A. Heilprin and the author.

The next paper was

GEOLOGICAL STRUCTURE OF THE UINTA MOUNTAINS

BY S. F. EMMONS

Remarks were made by C. P. Berkey. This paper forms pages 287–302 of this volume.

The following paper was read by title:

STRATIGRAPHY AND STRUCTURE OF THE UINTA RANGE

BY F. B. WEEKS

This paper has been printed as pages 427–448 of this volume.

The next paper was

STRUCTURE OF THE FRANKLIN MOUNTAINS, TEXAS

BY G. B. RICHARDSON*

The paper was discussed by W. M. Davis.

* Introduced by C. W. Hayes.

The following paper was read by title:

PROBABLE AGE OF THE MEGUMA (GOLD-BEARING) SERIES OF NOVA SCOTIA

BY J. EDMUND WOODMAN

[*Abstract*]

From the earliest studies to the present, the age of this series has been referred to in terms that are either vague or dogmatic without requisite evidence, and has been placed from the Silurian to the pre-Cambrian. The most commonly stated age is Lower Cambrian, the judgment being based (1) on "fossils," (2) on lithological resemblance to other supposed Cambrian rocks. For the most part, recent references have merely stated the age, assigning no reason for the belief.

The "fossils" are believed to be inorganic and the lithological resemblances untenable as evidence.

Of the possible lines of evidence not before referred to, graphite, lime, and concretions are of no direct value. Scolithus and certain as yet undescribed trails from Halifax are serviceable only as evidence of organic forms of some undetermined kind. Unconformities show that all the great events in the history of the series are pre-Devonian except the intrusions, which are lower Devonian; but thus far fail to narrow the problem further. The composition of younger rocks shows detritus from the Meguma in the Devonian and Carboniferous, but nothing more definite as yet.

Comparative structures are held to be especially important. The whole of the peninsula of Nova Scotia is built upon the Meguma series as a base, and the rocks of all ages show some sympathy in the strike of their axes, with the very marked orogenic type exhibited by that series. There are no rocks on the mainland of Nova Scotia containing Cambrian fossils, and the next age represented by fossils is the Ordovician. These rocks show a different orogenic type from the Meguma; so different as to lead to the conclusion that the mountain-building of the latter entirely preceded the Ordovician. As the formation of the bedded veins was contemporaneous with the folding in the Meguma, this places the chief features of its history into the Cambrian or before.

The thickness of the series (nearly 30,000 feet) is regarded as far too great to be assigned to the Cambrian without any direct evidence. The intrusives of the Meguma are all acid and abyssal, except some dioritic material on the northern margin of the great western bysmalith and a few dikes; and the amount of igneous rock is very great compared with the area of the sediments, one mass alone covering nearly 2,000 square miles. The granites intrude Silurian rocks in Annapolis, Digby, and Kings counties, but are older than the Horton series, mapped as Devonian, in Kings. They were intruded after all the main chapters in the history of the Meguma series had been enacted. No other rocks of the province are characterized thus, the next younger, the Ordovician, having basic hypabyssal types.

In previous literature correlation, direct or implied, has been made with various series from the Silurian down, those series themselves often of doubtful or unknown age. These correlations are regarded as unwarranted, and the

Figure 1.—Towers left by Erosion on the Lebanon Mountains

Figure 2.—Illustration of the Erosion of the Glandaria Limestone

EROSION FEATURES ON THE LEBANON MOUNTAINS

conclusion is reached that there are no sufficient data to permit correlation of the Meguma with any known series elsewhere; and the further conclusion that there is no positive evidence for regarding the Meguma as Cambrian, but that there is some warrant, not amounting to complete proof, for placing it in the pre-Cambrian.

It is expected that this paper will be printed in full in volume 19 of the Bulletin.

The last paper of the morning session in this section was

ARTIFICIAL PRODUCTION OF GNEISSIC STRUCTURES BY CRYSTALLIZATION UNDER STRESS

BY FRED. EUGENE WRIGHT

The second section of the Society elected George P. Merrill chairman and H. M. Ami secretary, and then proceeded with the reading of papers, as follows:

ORIGIN OF THE LEAD AND ZINC ORES IN MISSOURI

BY E. R. BUCKLEY

The paper was discussed by H. C. Hovey, H. M. Ami, and the author.

The next paper was

LEBANON GLACIER

BY G. FREDERICK WRIGHT

[*Abstract*]

Fifty years ago Sir Joseph Hooker reported that the cedars of Lebanon were growing upon a terminal moraine. Since that time references to the glaciation of the Lebanon mountains have been frequently made, and sweeping inferences drawn concerning the influence of the Lebanon glaciers upon the surrounding country, especially upon the water-levels in the Jordan valley. It was for the purpose of getting more accurate information upon the subject that in October, 1903, in company with Professor Alfred Day, of the Protestant College in Beirût, I set out to visit the principal grove of cedars, situated at the head of the Kadîsha river, east of Tripoli. The successful outcome of the expedition is largely due to Professor Day's comprehensive knowledge of the geology of the range, and I hereby acknowledge my great indebtedness to him.

The Lebanon mountains rise by a rapid and pretty uniform slope from the eastern shore of the Mediterranean to an average elevation of 5,000 or 6,000 feet, and opposite Beirût and Tripoli to elevations of from 8,000 to 10,000 feet, Jebel Sannîn, east of Beirût, being 8,567 feet above the sea and Jebel Makhmal, east of Tripoli, 10,225 feet above the sea. This range extends for a distance

of 95 miles northward from the Lîtany river. In structure the Lebanon range is an anticline, embracing three series of Cretaceous rocks. The lower series, about 3,000 feet in thickness, is, however, thought by some to be Jurassic. This rock is a thick layer of limestone, sparingly supplied with fossils, among which are sponges, corals, brachiopods, and the characteristic *Cidaris glandaria*, and is generally known as the Glandaria limestone. This formation is exposed at the bottom of many of the deep gorges which furrow the western flank of the mountain, and appears in foldings in several places at an altitude of from 4,000 to 5,000 feet, where the superincumbent rocks have been removed by erosion. It is this limestone which is so extensively weathered into castellated towers and so beautifully fluted by the rains, of which we shall presently speak.

The middle series consists of sandstone, soft limestone, and clay, with occasional exposures of thin strata of poor bituminous coal, with pyrites and efflorescent salts and deposits of low grade iron ore. From its reddish color this series can be distinguished a long distance away. About half way up the mountain, near Afka, in the headwaters of the Adonis river, there is a considerable exposure of volcanic ash around what seems to have been a well defined crater connected with the volcanic eruptions accompanying the elevation of the range.

The third series is composed of hippurite limestone, and forms the summit of the range, resting there in nearly horizontal strata and attaining a thickness of from 3,000 to 5,000 feet. Upon the flanks of the mountain these strata are much contorted and have been extensively removed by erosion.

The eastern limb of the Lebanon anticline descends very precipitously into the valley of Beka'a, of Cœlesyria, which separates Lebanon from the parallel range of Anti-Lebanon, from 10 to 15 miles distant. Near Zahleh, on the east side, at an elevation of between 3,000 and 4,000 feet, occur porous sandstones and clays, with fossils of Miocene age.

In order more thoroughly to test the question of the general glaciation of the range, we traversed the region diagonally across the western flank of the mountain from Beirût to Jebel Makhmal, at whose western base the Kadîsha river has its source amid the cedars of Lebanon. The distance in a direct line is about 30 miles. The route, however, was a zigzag one, leading first up the Nahr-el-Kelb to the natural bridge at the head of the north fork, and then over the divide to the Adonis river, at Afka, and thence across the headwaters of the Jozek river to Bsherreh, in the upper portion of the Kadîsha. Throughout the larger part of this distance we were immediately underneath the summits of the range upon the east, where we should have observed ancient moraines and other signs of glaciation, if any had occurred; but there was a total absence of such signs, except possibly near Afka, where the debris accumulated at the base of the summit had somewhat the appearance of till; and again, near Akûra, where an immense amount of debris having accumulated, it was gradually sliding down to a lower level, as it was undermined by the northern branch of the Adonis river; but throughout this entire distance the sculpturing of the mountain side revealed the action of water rather than of ice. The deep and frequent gorges were wholly due to the action of water, while innumerable castellated and fantastically sculptured projections of the lower limestone conclusively demonstrated that ice had nothing to do with the general sculpturing of the mountain side.

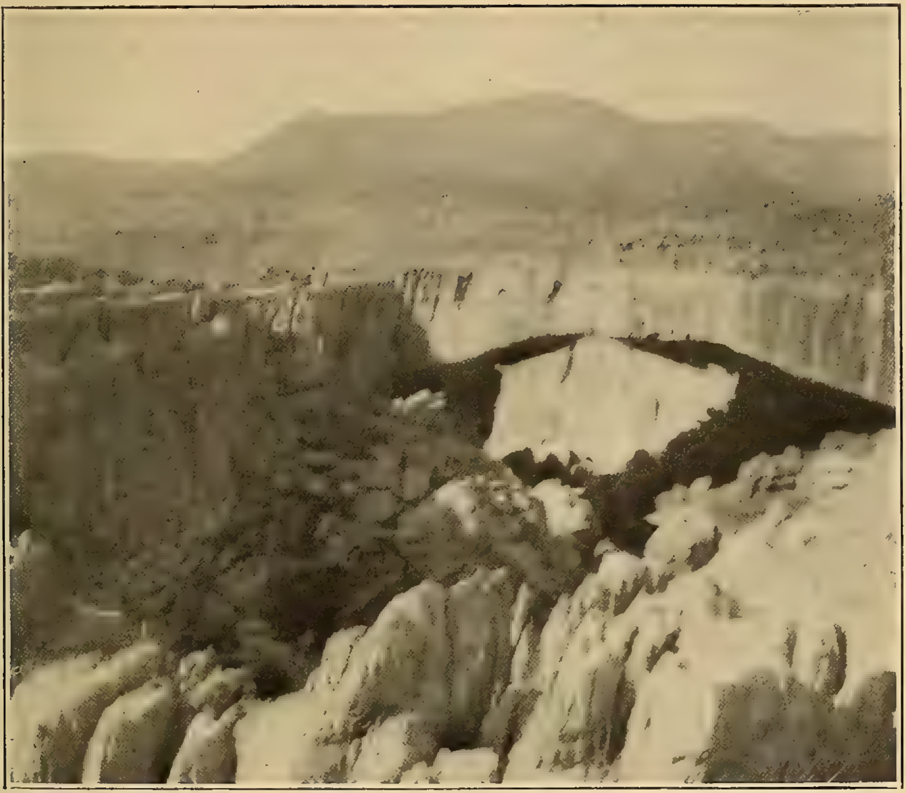

FIGURE 1.—NATURAL BRIDGE HALF WAY UP THE MOUNTAIN

Summit of upper limestone in the background

FIGURE 2.—GORGE OF THE MIDDLE KADISHA

TOPOGRAPHIC FEATURES OF THE LEBANON MOUNTAINS

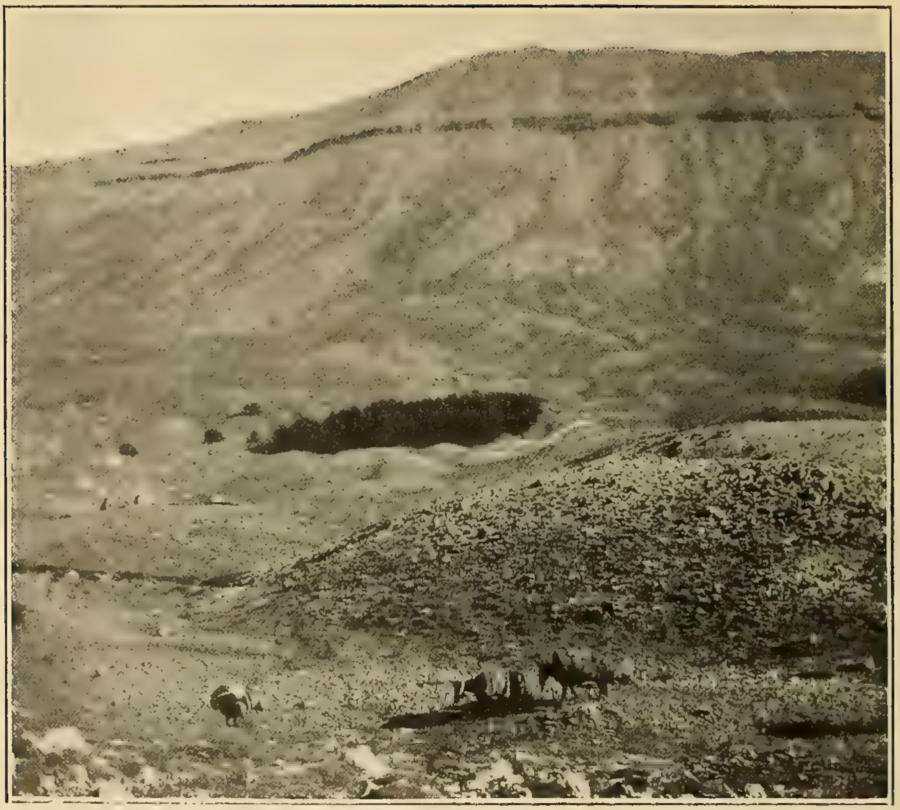

FIGURE 1.—DISTANT VIEW OF THE CEDARS, SHOWING THE MORAINE SURFACE

FIGURE 2.—VIEW FROM THE UPPER PART OF THE MORAINE TOWARD THE SUMMIT

Showing the notch down through which the glacier descended

CEDARS OF THE LEBANON MOUNTAINS

It was only as we approached Bsherreh, near the headwaters of the Kadîsha, that true signs of glaciation appeared. Here, at an elevation of 5,300 feet, the front of a moraine extends from one side of the valley to the other, a distance of about four miles. The moraine consists of limestone fragments of all sizes from vast blocks down to fine powder, derived from the hippurite limestone forming the crest of the mountain a few miles back. In the middle of the valley the precipitous face of this moraine is several hundred feet thick, and is suffering erosion from a powerful current of water which issues as a spring from its base, this being the drainage from the whole area of the moraine back of it. Through the action of this stream a triangular area has been eroded from the moraine, ending in an acute angle, where the water emerges from beneath the surface. No scratched stones were found in the moraine, which is doubtless due to the fact that the material has been brought from only a short distance, and probably had for the most part been borne upon the surface of the ice, whither it had fallen from the overhanging ledges at the summit of the mountain. But that it was of glacial origin is certain from the promiscuous intermingling of coarse and fine fragments and from the impossibility of its having been brought into position through the action of gravity upon an ordinary talus, and still further from the topography of the area extending 4 or 5 miles back toward the head of the valley.

Upon ascending to the summit of this moraine, we find that it extends about 5 miles toward the apex of the valley and presents everywhere the knoll and bowl topography characteristic of a true terminal moraine. The grove of cedars which makes the region celebrated is growing upon the upper part of this moraine, at an elevation of 6,300 feet above the sea. Standing on the eastern edge of this grove, one sees the highest summit of the Lebanon range, some 3 or 4 miles distant, with a triangular depression, 100 or 200 feet below him, which was evidently occupied by ice during the last stages of the declining glacier, which had poured down from the small plateau on the summit through a narrow trough, clearly visible, and spread out as it had opportunity over the expanding area of the valley.

Upon ascending the summit, one finds a plateau, of several square miles, where the snows gathered during the Glacial epoch in sufficient quantity to supply the glacial ice that pushed down into the valley of the Kadîsha, a distance of 8 or 9 miles, and to a level which is about one-half of the total height of the mountain above the sea.

Upon descending the mountain into Cœlesyria toward Ba'albek, we could find no signs of glacial action. In the local valley of a small stream which runs between the eastern foothills and the main range of Lebanon and disappears in the sink of the Yamuneh, there is an immense accumulation of gravel, which in places appears in ridgelike accumulations, extending across the valley, which was evidently deposited by streams rushing down the steep side of the mountain and projecting the material brought down far out beyond the base, while occasionally there were immense boulders nearly a quarter of a mile from the base, which probably were carried out so far by their own momentum, attained in rolling down from a great height.

This moraine at the head of the Kadîsha river, upon which the cedars of Lebanon are growing, has all the marks of youth which characterize the glacial deposits of America and Europe. The bowls upon the surface have not

been extensively filled up with sediment and the knolls have not been greatly diminished in height. The erosion by the stream issuing from the front of the glacier is comparatively limited in extent. More careful study of it may yet shed some light on the time that has elapsed since glacial accumulation ceased at the margin, but at present we have no data from which to make calculations.

An interesting subject of inquiry concerns the relation of this glacier to the ancient water-levels in the Jordan valley. It has been pretty generally assumed that the expansion of the Dead sea shown by the sedimentary terraces which surround the valley at an elevation of 650 feet, and, as Hull maintains, at an elevation of 1,400 feet, was the direct result of the glacial conditions in the Lebanon and Anti-Lebanon mountains. Even though no glacial streams could reach the Jordan valley from the Lebanon mountains, it is maintained that the increased precipitation and diminished evaporation of the region during that epoch would result in filling the Jordan valley with a body of water 200 miles long, 30 or 40 miles wide, and at its southern end 2,000 feet deep.

It is possible, however, to interpret the facts in a different way, and make the glaciation of the Lebanon mountains an effect of the increased area of the Dead sea rather than the cause. There is abundant evidence that the land all along the shore of the Mediterranean has risen 250 or 300 feet during the most recent geological era. Raised beaches containing shells of the same species that are now living in the Red sea and the Mediterranean are found near the pyramids in Egypt and in the vicinity of Jaffa and Lattakia, on the eastern shore of the Mediterranean. Now, if the land of this region were to be depressed 300 feet, it would admit the water of the Mediterranean into the Jordan depression through the valley of Esdraelon between Nazareth and mount Carmel. It is quite possible that the filling of the valley with water during that depression may have been the cause of the greater precipitation which produced the conditions favorable to the formation of the Lebanon glacier. If so, the various means we have of estimating the date of that depression of land may aid us in determining the approximate date of the Lebanon glacier. The general aspect of this moraine and the specific evidence bearing on the date of the enlargement of the Dead sea all point to these occurrences as comparatively modern events, estimated in tens of thousands of years rather than of hundreds of thousands of years.

Remarks were made by H. C. Hovey and the author.

ICE PRESENT DURING THE FORMATION OF GLACIAL TERRACES

BY F. P. GULLIVER

[*Abstract*]

This paper described with maps and latern slides some glacial deposits along the Connecticut, Thames, and Quinebaug rivers which have usually been classed with the terraces formed by the down-cutting of the rivers. An example of terraces which have surely been carved by river action is found in the Westfield river west of Springfield, Massachusetts.

The deposits described along the Connecticut rivers were contrasted with those found at Westfield, and it was shown that they must have been formed

SNOW "CAVE" ON THE SUMMIT OF LEBANON

Showing stones incorporated in the strata of ice

before the ice had completely melted from the valleys. These deposits were therefore forms of aggradation and not forms produced by degradation.

Typical eskers, deltas, and kettle-holes are associated with these so-called terraces; and even where these deposits have the characteristic form of river cut terraces, cross-sections as revealed by railway or other cuts show delta structure rather than the structure of alluvial flood-plains. The delta lobes point either down stream or into side valleys, and there are frequently found unfilled portions of the main preglacial valley and of its tributaries below the level of the delta-terrace, between the delta-terrace and the rock walls of the older valley.

The discussion was participated in by F. G. Clapp, R. D. Salisbury, F. Leverett, Alden, and the author.

PLEISTOCENE GLACIAL PHENOMENA OF THE BOLIVIAN PLATEAU

BY W. G. TIGHT

The paper was discussed by H. F. Reid and C. H. Hitchcock.

PREGLACIAL DRAINAGE IN THE MISSISSIPPI VALLEY, A WORKING HYPOTHESIS

BY W. G. TIGHT

Remarks were made by F. Leverett and F. Carney.

The following paper was read by title:

GLACIAL FLOWAGE OVER NEW ENGLAND

BY J. B. WOODWORTH

COMPLEXITY OF THE GLACIAL PERIOD IN NORTHEASTERN NEW ENGLAND

BY FREDERICK C. CLAPP

Discussion by F. Leverett, C. H. Hitchcock, Alden, H. M. Ami, and the author. This paper is printed as pages 505-556 of this volume.

GLACIAL LAKE MEMPHREMAGOG

BY C. H. HITCHCOCK

[*Abstract*]

The existence of this lake was first announced at the meeting of the society in 1894.* Recent studies show that it was tributary to Glacial Lake Champlain by way of both the La Moille and Winooski valleys. When the ice filled the Champlain valley to the depth of a thousand feet the impounded water on the east side could have reached the Connecticut basin by way of White river.

* Bull. Geol. Soc. Am., vol. 6, p. 460.

Further descriptions of this rather unique body of water will be found presented in a "Report on the Champlain deposits of northern Vermont," printed as a part of the Fifth Report upon the Geology of Vermont, 1906, by Professor G. H. Perkins.

Discussion by G. F. Wright and C. H. Richardson.

PRE-WISCONSIN DRIFT IN THE FINGER LAKE REGION OF NEW YORK

BY FRANK CARNEY†

The paper was discussed by R. S. Tarr and the author.

This paper has been published in the Journal of Geology, volume xv, 1907, pages 571–585.

WAVE-CUT TERRACES IN KEUKA VALLEY OLDER THAN THE RECESSION STAGE OF WISCONSIN ICE

BY FRANK CARNEY

The paper was discussed by F. G. Clapp. This paper has been published in the American Journal of Science, volume xxiii, 1907. pages 325–335.

The section adjourned for luncheon.

The section of the Society convened again at 2.15 o'clock p m, with the first section (physical and structural geology) under the chairmanship of the Acting President.

The first paper read was

ORIGIN OF METEOR CRATER (COON BUTTE), ARIZONA

BY H. L. FAIRCHILD

Remarks were made by A. C. Lane and G. P. Merrill. The paper forms pages 493-504 of this volume.

The next paper read was

AFTON CRATERS OF SOUTHERN NEW MEXICO

BY W. T. LEE

This paper is printed as pages 211-220 of this volume.

The next paper read was

VOLCANIC NECKS OF THE MOUNT TAYLOR REGION, NEW MEXICO

BY D. W. JOHNSON*

This paper is printed as pages 303-324 of this volume.

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† Introduced by H. L. Fairchild.

* Introduced by Ralph Arnold.

The following paper was then read:

*EARTH-FLOWS AT THE TIME OF THE SAN FRANCISCO EARTHQUAKE**

BY ROBERT ANDERSON

[*Abstract*]

Landslides of different kinds resulted in great numbers from the California earthquake of April 18, 1906. The term *earth-flow* is applied to landslides having the nature of flows of surface material partially saturated with water that were produced as a result of the earthquake by the sudden accession of water to points on the surface. Underground conduits of water suffered disturbances from the earthquake shock, and seepages occurred at the surface at new points or, in increased amounts, at old points of moisture concentration. In certain cases the water seems to have risen with a gush, as if actually squeezed from the hills. The effect of this abnormal supply of water was a saturation and loosening of the subsoil and a flowing movement of the surface debris away from areas so affected. The original loosening was aided by the vibratory movement of the shock, especially at points where some moisture had already gathered in the ground, the intensity of the shock in moist ground having been much greater than elsewhere. The water was the chief agent in causing the movement of the loosened material, as a result of the weight that it added and the semi-fluid nature that it gave to the mass. The process was usually one of sapping and undermining, the surface sod remaining dry and being broken into blocks and transported in a comparatively little disturbed position on a plastic substratum. At some of the earth-flows water continued to flow after the earthquake where it had not flowed before.

Earth-flows were of frequent occurrence in the Coast ranges, the writer finding them numerous on the San Francisco peninsula and in the Santa Cruz mountains within a score of miles of the fault, and what appeared to be flows of similar origin at a much greater distance from the epicentrum. They were formed on gentle as well as steep slopes, and both in previously dry drainage depressions and on convex hillsides. In the largest flows thousands of tons of earth and rock detritus were removed and carried hundreds of yards, leaving great cavities. In one case a hole ten feet deep was excavated over an area of nearly an acre on a five-degree slope, and the material removed was spread over two acres.

Such earth-flows, as well as the related slumps caused by earthquakes, in the case of which it is not easy to determine whether or not the slide or flow of soil has been aided by a suddenly increased water supply, are of special geologic importance for the reason that they aid in the initiation of drainage lines and the furtherance of degradation.

The following paper was read by R. B. Moore:

RADIO-ACTIVITY OF THE THERMAL WATERS OF YELLOWSTONE NATIONAL PARK

BY HERMAN SCHLUNDT AND RICHARD B. MOORE †

* This subject is treated more fully in the report of the Earthquake Commission being published by the Carnegie Institution of Washington.

† Introduced by C. W. Hayes.

Remarks were made by J. F. Kemp and A. C. Lane.

The following paper was then read by title:

OCCURRENCE OF UNUSUALLY LARGE CALCITE CRYSTALS IN NEW YORK STATE

BY D. H. NEWLAND

The next paper was

ASYMMETRIC DIFFERENTIATION IN A BATHYLITH OF ADIRONDACK SYENITE

BY H. P. CUSHING

The paper was discussed by A. C. Lane. It forms pages 477-492 of this volume.

The following paper was then read by title:

FORMATION OF LEUCITE IN IGNEOUS ROCKS

BY HENRY S. WASHINGTON

The next paper was

GENETIC RELATIONS OF SOME GRANITIC DIKES

BY ALFRED C. LANE

Contents

1. Effect of Difference of Conditions on Crystallization

One of the fundamental principles in considering the coarseness of grain of rocks is that, other things being equal, the less the difference between the conditions before and after crystallization, the coarser will be the crystallization. When the difference of conditions is small, the rate of change from the one state to the other will also be slow, and the crystallization proportionately coarse. We note this in the laboratory, where the coarse crystals are formed from the relatively cool or tepid solutions, and in the kitchen, where the conditions for making the coarsely crystallized rock candy are sharply contrasted with rapid cooling and stirring of a hot syrup required to make a "fondant," which forms the center of chocolate creams. This principle is one of the first consequences of the proposition that the grain is proportional to the slowness of cooling.*

* Annual Report Geological Survey of Michigan, 1903, p. 212.

2. Application to Pegmatites

As applied to the giant granites, the pegmatites, the ultra coarse-grained rocks, the principle mentioned suggests that the rock broth, or magma, from which they formed was not so different in its physical conditions, such as temperature, pressure, and gas saturation, from the surrounding rock. They might accordingly be formed by a raising of the rock to a point where any part of its constituents became fluid, or, what amounts to the same thing, where its inherent rock moisture has its solvent power markedly increased. This might be the origin of what might be called segregation pegmatites. But, on the other hand, we may consider them products of an ordinary granitic magma, occurring in the granite mass or in its contact zone.

The suggestion would then be that they should be a relatively late product of it, after its contact zone had been heated up and after the magma had lost some of its original fluidity, heat or gas, and was on the point of crystallizing—indeed, had perhaps largely crystallized already, leaving only a residual anchieutectic* magma.

3. Observations in the Huron Mountains

The foregoing reflections came to me from some observations in the Huron mountains. The locations where these facts may be observed are so very numerous that they can hardly be particularized, and in fact Professor A. E. Seaman, of the Houghton College of Mines, who has vastly wider experience than I of this region, says, also, that the pegmatites cut the aplites, so far as he has seen.†

The country rock is a series of banded gneisses and hornblende-schists and amphibolites, Keewatin-Laurentian, forming anticlinal regions between the basins of Huronian rocks. The country was mapped by the first surveyors as "syenite and gneissoid granite," and has since been mapped with the Azoic, Laurentian, and Archean. At times the banding is well marked, strikingly like that of a series of sediments.‡

The amount of hornblende varies greatly. The strike of the banding is pretty constantly west northwest—that is, parallel to the axis of the synclinal of Huronian rocks that lies south.

This country rock is cut by various classes of dikes.

(1) In the first place, it is cut by the group of granitic dikes which we wish to study.

(2) They are cut by a group of uralite diabases, epidiorites, etcetera, which are probably of Huronian age.

(3) Latest are diabases, like that of Marquette, which are presumably Keweenawan.§

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* Vogt's word—almost eutectic. Compare also my paper on the rôle of possible eutectics in rock magmas, Journal of Geology, 1904, pp. 86, 89.

† However, this paper is based mainly on notes and sketches on Huron mountain, section 39, township 52, range 29, and sections 24 and 25 adjacent; also mount Homer, section 31, township 52, range 28, near Mountain lake; also Pine lake, in section 28, township 52, range 28, especially, and section 4, township 52 north, range 27.

‡ So around Ives lake.

§ See Geological Survey of Michigan, vol. vi, part i, chapter x.

The coarsest country rock is a hornblende-gneiss, but the individual grains are rarely over 2 to 3 millimeters across. A tendency to porphyritic texture, like that of the Republic granite, is rare and not pronounced.*

In but few places does the hornblendic country rock fail entirely to be cut by red dikes composed mainly of quartz and feldspar. There is but little sign of one being in excess over the other, and they are probably nearly eutectic.

Generally the rock is riddled with them and they stand in relief, and may show glacial striæ when the rest of the rock does not. They are close welded to the country rock, so that it is not very difficult to get a piece showing both sides of the contact. Indeed, frost will sometimes spall off a section clear across a small dike including a little of the country rock on either side. Sometimes, as at the top of Huron mountain, they are so abundant that at first sight the country rock appears like a lot of basic fragments or secretions inclosed in a general mass of granite; yet it is very easy to see that through all these apparent fragments there is a constant strike and dip of the schistosity in which the red granitic matter does not partake. A more careful examination, moreover, shows the nexus of dikes which make up the general granitic effect.

Now we may for convenience sake divide these dikes into (*a*) those whose grain is finer than the country rock, less than 2 to 3 millimeters, often about 1 millimeter, which we will call aplites; (*b*) those whose grain is coarser than the country rock, often 50 millimeters or so, which we may call pegmatites. Exceedingly coarse pegmatites I did not see.

We find the following variation of grain in individual dikes:

1. Dikes aplitic in general grain, with coarser border.
2. Dikes aplitic, but with coarser pegmatite bands near, but not at, the side.
3. Dikes granitic in grain, with coarser pegmatitic border.
4. Dikes with a fine-grained margin and coarser center. This type seems rare, and in many, but not all, cases may be explained by the splitting of a fine-grained dike by a later coarse-grained one.
5. In many cases the grain seems uniform—at least to casual inspection—throughout.

It is not uncommon to find a concentration of the darker minerals, the mica or hornblende, at the center of the dike.

A very striking dike of pegmatite (figure 1) on mount Homer, 28 inches wide, shows irregular prisms of quartz growing from the margin, while the center is made up of patches of graphic granite. Figure 1 is, however, only a memory sketch from notes at the time.†

In a rough way the larger pegmatites are also coarser in grain; but while both the pegmatites and the aplites are close welded and have about the

* I noticed a trace with feldspar grains 10 millimeters long on the south side of Second Pine lake. A splendid porphyritic rock at the foot of mount Homer, and near J. M. Longyear's house, on Ives lake, I take to be a Huronian dike.

† I remember seeing a similar structure in a pegmatite dike on the north side of Sand lake, Proudfoot township, Parry sound, Canada. The dike was 32 inches broad, and quartz radiated from each side for about 4 inches, while the dike as a whole was made up of biotite, muscovite, feldspar, and quartz in good-sized crystals.

same tendency to follow straight lines or cut irregularly across the country rock, *with perhaps no exception the coarser dikes cut the aplites.*

4. Conclusions

The inference seems warranted that the grantic dikes, aplites and pegmatites together, represent one period of invasion of the Keewatin hornblende schists and gneisses by the granitic magma.*

In the beginning the difference of conditions of country rock and magma was considerable. Still the absence of fine-grained margins shows that the conditions of solidification of the granitic magma (pressure, temperature, mineralizers) were nearer the conditions of the country rock than those of

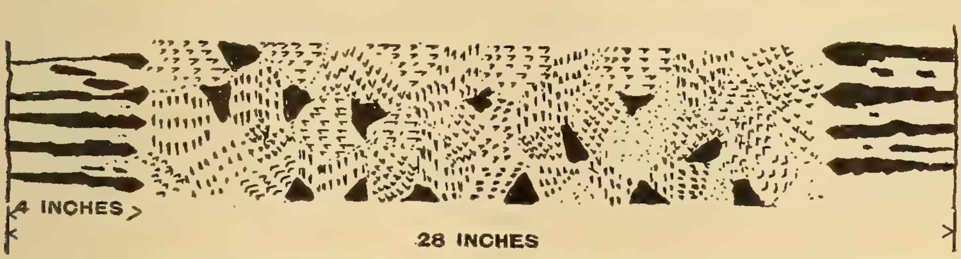

Figure 1.—*Structure of a granitic Dike on Mount Homer.*

The quartz grows out for 4 inches (100 millimeters) from the margin in rude prismatic forms. The rest of the way is mainly filled with patches of graphic granite. Quartz is black; feldspar white.

the magma, or at times just about half way, and then the aplitic dikes formed.

Later the temperature of the country rock rose, or it otherwise approached the conditions of liquefaction for granite. The granitic magma also cooled. At any rate, the interval decreased† from the conditions of consolidation of the dikes to the conditions of the country rock, and so the later pegmatites are coarser. If the granitic magma did not also cool, they would become even more than the aplite uniform in grain from center to margin except so far as it was modified by a tendency of substances existing in excess of the eutectic to crystallize out earlier, or a tendency to grow first from the walls, as in veins, the same tendency that makes nuclei hasten the crystallization of an undercooled fluid.

Such tendencies may explain the coarser grain at the margin (see figure 1) in part, but it may also be explained by supposing that the granitic magma cooled as fast as the country rock heated, so that the conditions of consolidation were about half way between them.

Criticism has been made of my studies of grain that I have not allowed enough for undercooling and varying velocity of crystallization.‡

I think it will be found that I have always recognized that other factors than rate of cooling were of importance, and my mathematical work only gives a first approximation, but I have insisted that observation shows that often it has been of leading importance, and my results have been obtained

*Compare Rosenbusch, "Elemente der Gesteinslehre," p. 220.

† v of my annual report, Geological Survey of Michigan for 1903, pp. 211 and 212.

‡ Doelter: Petrogenesis, p. 45.

by definite, if not exact, numerical measurements, showing that the grain in some cases did vary as it would if the rate of cooling were the dominant factor. It must be remembered, too, that it is more than probable that most igneous magmas contain catalyzers—gases of one kind or another that promote liquidity and restrain viscosity—and that, as regards the later formed minerals, the earlier act as centers or nuclei of crystallization, notably orthite in granite, promoting crystallization and preventing undercooling, thus making the grain more responsive to the rate of cooling. Indeed, the jars recorded by seismographs may have some effect.

To give more concrete expression to our conclusions, let us insert some hypothetical figures:

Suppose the hornblendic country rock was at first at 100 + degrees centigrade (the close welded contacts suggest that it was not wet). The temperature of formation of the aplites was probably not above 800 degrees centigrade (the inversion point of quartz to tridymite, according to Day and Allen, is about 760 degrees at ordinary pressures). If so, the initial temperature of the aplite-forming magma was a little less than 1,500 degrees $(2 \times 800 - 100) + 100$; but by the time the coarsest pegmatites of this region formed the country rock temperature may have risen to over 700 degrees and the magma temperature fallen to less than 900 degrees, if we suppose the grain to be 50 times greater in the pegmatite than in the aplite.

This is merely an illustration, for I am inclined to think that the interchange of vapor pressure, or gases, is quite as important as the interchange of heat, and the growth of quartz crystals from the margin of the pegmatites is especially due to it.

The next paper was

OPHITIC TEXTURE

BY A. C. LANE

[*Abstract*]

Ophitic texture is not a mere synonym of the diabasic, but a variety of the poikilitic* made by the inclosure of tabular, or lath-shaped, feldspar in augite, by which a mottled appearance is often produced, like that of some ophidians (figure 1, plate 70). This mottling, when coarse enough, appears:

(1) On smooth, dull, or matte surfaces, like those of pebbles or diamond drill cores (figure 2, plate 70).

(2) On fresh fracture very faintly, but in the sunlight the reflection on large, interrupted cleavage faces of the augite produces the effect called by Pumpelly "luster-mottling."

(3) On joints and rifts the pattern is brought out in a variety of color effects, according to the type of weathering.

(4) On weathered surfaces that are also exposed to erosion a lumpy, warty, or pock-marked appearance is produced, which gave rise to the name "varioloid greenstone," as applied to ophitic melaphyres (plate 71).

* Geological Survey of Michigan, vol. vi, part 1, pp. 51, 227; Journal of Geology, 1906, p. 705.

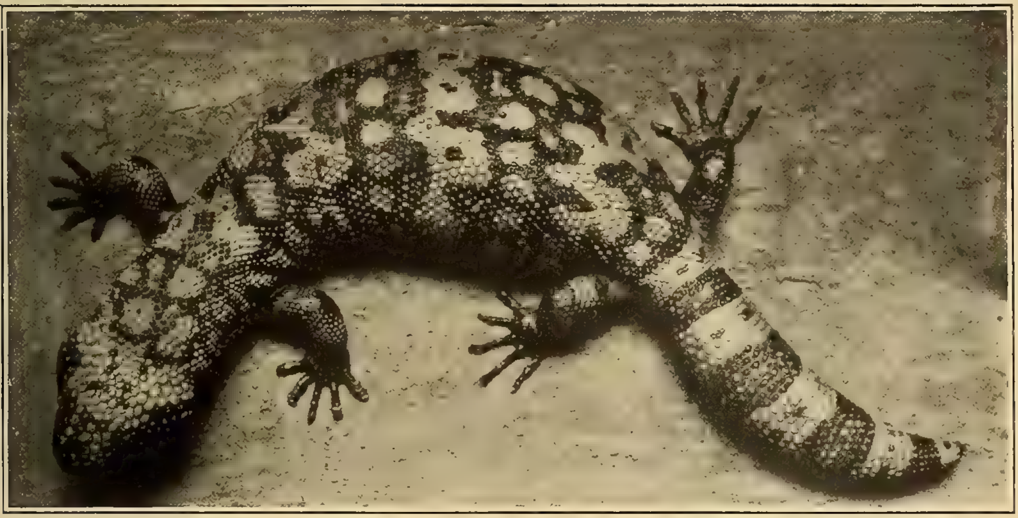

Figure 1.—Photograph of Ophidian (Gila Monster)

Showing ophitic pattern. Kindness of Zoological Department of Michigan Agricultural College

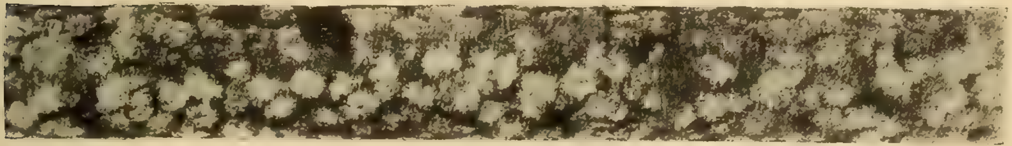

Figure 2.—Diamond Drill Core

Ophitic mottling brought out near chlorite seam. Kindness of W. J. Penhallegon

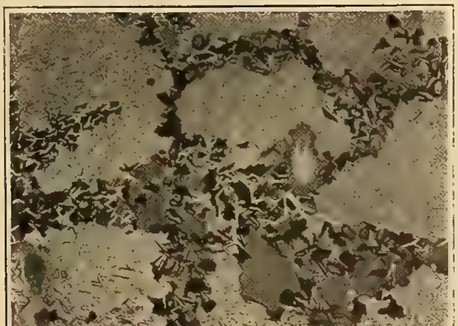

Figure 3.—Ophitic Texture in Thin-section

After Irving. Monograph v, plate ix

OPHITIC TEXTURE

BLUFF BACK OF DELAWARE MINE

Taken by W. J. Penhallegon, August, 1907, to illustrate effect of weathering on ophitic texture. The white object is a slide rule six inches long and one inch wide. The exposure is about 100 feet from the base of the "greenstone"

(5) Where weathering goes on faster than erosion, the rock is often broken down into a coarse gravel, each grain of which is likely to be a single augite crystal.

(6) The thin-section (figure 3, plate 70) shows the texture plainly, and how it is produced by the fact that the augite, while readily enveloping the labradorite, crowds ahead of it the corroded remnants of the olivine (at whose expense it is formed) as well as the iron oxide.

The following paper was then read by title:

OCCURRENCE OF DIAMONDS IN NORTH AMERICA

BY GEORGE F. KUNZ

The following paper was then read:

SILVER-GOLD ORES AT SAN PEDRO DE GUANACEVI, DURANGO, MEXICO

BY FREDERICK B. PECK

The following paper was then read by title and transferred with permission of the author to Section E, American Association for the Advancement of Science, and read there December 31.

PERSPECTIVE VIEW OF THE SUBMARINE CANYON OF THE HUDSON RIVER

BY J. W. SPENCER

The following papers were read by title:

TITANIFEROUS BASALTS OF THE WESTERN MEDITERRANEAN

BY H. S. WASHINGTON

THE PALEOZOIC SECTION OF THE UPPER YUKON

BY A. H. BROOKS AND E. M. KINDLE

STRATIGRAPHIC SUCCESSION NORTH OF COOK INLET, ALASKA

BY SIDNEY PAIGE AND ADOLPH KNOPP *

This paper appears as pages 325-332 of this volume.

SEISMOLOGICAL OBSERVATIONS OF THE UNITED STATES

BY H. F. REID

The following paper was read by title and was transferred with per-

* Introduced by A. H. Brooks.

mission of the author to Section E, American Association for the Advancement of Science, where it was read December 31, 1906:

CHARLES WILLSON PEALE'S PAINTING, "THE EXHUMING OF THE FIRST AMERICAN MASTODON"

BY ARTHUR BARNEVELD BIBBINS

Charles Willson Peale, who was born in Queen Anne county, Maryland, in 1741, and who became known as "The Artist of the Revolution," was one of the pioneers—perhaps the Nestor—of American vertebrate paleontology. Although very few of his scores of paintings relate to this subject, one which has lately come to the writer's notice, with the correspondence by the Peales and others relating to the subject of the painting, clearly demonstrates the artist's keen, intelligent, and practical interest in this direction—the most advanced of his time in this country.

The canvas measures 5 by 6 feet and is known as "The Exhuming of the First American Mastodon." It is signed "C. W. Peale" and dated 1806.

The scene portrays the unearthing of the first of the two mastodons which the artist obtained near Newburg-on-the-Hudson in 1801, and which were the first approximately complete skeletons found in this country. This century-old picture has recently been brought to scientific notice, since it has come into the possession of the family of one of the artist's lineal descendants, by whose kind permission this reproduction of the painting is shown.

The canvas is well preserved and its detail clear and distinct. The artist is represented as personally supervising the excavation. Members of his family, including his wife, Rembrandt and his wife, Titian and James Peale, and several scientific worthies of the day, are in attendance, and the whole countryside is, as will be seen, astir with the unwonted activity in their midst.

Rembrandt Peale, the no less celebrated son of the elder Peale, has left a very graphic account of the labors attending the excavation. This rare little pamphlet was written in London in 1803, while the incidents were vividly in mind. A copy of it was brought to my notice at the Maryland Historical Society, in Baltimore, and I have been much gratified to find yet another copy here, in the library of the American Museum of Natural History, which has been kindly loaned me for this occasion. I will refer to a few paragraphs from it.

According to Rembrandt Peale's account, his father had received word in the spring of 1801 that in the previous autumn an old farmer, in digging into a marl pit in the vicinity of Newburg, had discovered a number of gigantic bones, which he heaped on the floor of his granary or garret.

The thigh bone, 3 feet 9 inches in length, was first discovered, and for several succeeding days 100 men were encouraged by the physicians in the neighborhood to continue their efforts with very considerable success.

By the use of "rum" in too great abundance, however, the men became unruly and impatient and nearly destroyed the skeleton, and by using oxen and chains to drag the bones forth from the clay or marl, the head, hips, and tusks were much broken and many parts left behind. So great a quantity

THE EXHUMING OF THE FIRST AMERICAN MASTODON

of water from copious springs, bursting from the bottom, rose upon the men that it required several score of hands "to lade it out with milk-pails, buckets, and bowls." After the fourth day the attempt was given up, and it was in this condition when Peale arrived upon the scene, in 1801. Peale purchased the excavated bones from the farmer for a small sum, reenforced by the judicious gift of gowns to his wife and daughter and a gun to his son.

All necessary articles for the excavation had been provided from New York—pumps, ropes, pulleys, etcetera—and after weeks of close labor, a millwright fashioned the machinery and completed a large scaffold and a wheel 20 feet in diameter, wide enough for three or four men to walk abreast in, to supply tread power. A rope around this turned a spindle, which worked a chain of buckets. The water was raised and emptied into a trough and conveyed into a basin a short distance away. A ship's pump assisted the work, and later a pair of barrels, raised by a crane, removed the mud.

Several weeks of unremitting work, during which bank after bank fell in, resulted in the discovery of but a few additional bones, while the 25 hands which Peale employed at high wages were kept at their task partly by their eagerness to uncover the head and under jaw.

Finally the work was relinquished, but again taken up 20 miles west of the Hudson, where the particular bones desired were found in another mastodon, together with others sufficient to fashion two skeletons. One was exhibited in Peale's museum, which he had recently opened in Philadelphia and where he gave lectures upon natural history. Family tradition recites that after the skeleton was mounted in the Philadelphia museum a celebration and dinner were given beneath it.

The other was exhibited by his son Rembrandt in Baltimore and became the nucleus of the "Peale museum" there, which he erected and which bears upon its front to this day the faded legend:

"Erected by Rembrandt Peale.
"Baltimore Museum, 1817–1830
"City Hall, 1830"

Both the Philadelphia and the Baltimore museums, the former started in 1802 and the latter about 1813, appear to have resulted from the Newburg finds; and, since these were the first public natural history museums in America, must we not credit the Peales as well with the nestorship of American public museums?

The scope of their interest along this line is suggested by another family tradition,* which relates that while the elder Peale and Baron von Humboldt were being entertained at a formal "three o'clock dinner" by President Monroe, the guests improved this opportunity by asking the President to try to induce Congress to establish a National museum, and that Peale returned from the interview much elated by the belief that some action would shortly be taken.

Tradition also adds that Peale was first induced to undertake the exhuming of the mastodon by Von Humboldt, who had visited this country before and been entertained by the artist.

* This is stated in C. W. Peale's diary, *not* tradition.

Of the find itself, Dr John C. Warren, the New England author of a monograph on the mastodon, said in 1852 that "there probably never has been a discovery in science which excited more intense interest." He relates that Peale's mastodons were at that time the greatest curiosities in natural history in America, and virtually credits the artist with the awakening in this country of the first genuine interest in vertebrate paleontology.

Of considerable interest in connection with this painting is a letter written by Peale, just after its completion, to the celebrated Benjamin West, whose early pupil he had been. It appears in the Pennsylvania Magazine of History and Biography, volume ix, 1885, pages 130–132.

I quote a single paragraph:

"PHILADELPHIA, *December 16, 1807.*

"DEAR SIR: . . . .

"Desiring to represent the scene of getting up the Mammoth bones, it being a very interesting article of the museum, last summer I undertook a picture of it. This picture contains a great number of figures, for while I was engaged in that labour my exertions excited the admiration of all the people for a considerable distance round that country; few people could conceive why I should incur so much expense to get the bones. Although I have introduced upwards of 50 figures, yet the number of spectators in fine weather amounted to hundreds. Eighteen of my figures are portraits, having taken advantage of taking most of this number of my family. I have introduced my painting this picture in order to state to you that I still doubted my ability of making a tolerable picture, and at the commencement of it I made use of a temporary easel and other apparatus for painting; however, as I advanced in the work it seemed to engross my whole attention, and I really took pleasure in painting from morn till night and even to use lamplight. I then ordered the cabinet-maker to make me a commodious mahogany easel, &c.; so instead of burning my pencils and totally quitting the art, as I thought very probably would be the case, I found it much less difficult than I imagined and have ever since regretted that I had not taken a larger canvas and devoted more time to give a higher finish to the piece. I often say that the aged ought not to be discouraged from undertaking works of improvement. . . .

"Make my most respectful compliments to Mrs. West, and believe me with great esteem, your friend,

"C. W. PEALE.

"Mr. BENJAMIN WEST,
London."

The painting is at present in the custody of the Woman's College of Baltimore, to which it was loaned by Mrs. Harry White, of Massachusetts, and where its centenary unveiling will shortly occur.

RELATIONS OF THE ITHACA AND CHEMUNG FAUNAS OF WESTERN MARYLAND

BY C. K. SWARTZ

This paper was transferred with the author's consent to Section E,

American Association for the Advancement of Science, and read there at the session of December 31, 1906.

The section adjourned to the room occupied by the second section, where papers were still being read.

The second section met at 2.15 o'clock p m and reorganized by electing A. P. Coleman chairman and Collier Cobb secretary. The stratigraphic papers on the program were taken up.

The first paper was read by title:

DISCOVERY OF CAMBRIAN ROCKS IN SOUTHEASTERN CALIFORNIA

BY N. H. DARTON

The next paper was

LIMESTONES OF WESTCHESTER AND PUTNAM COUNTIES, NEW YORK

BY CHARLES P. BERKEY

The following paper was then read:

GALENA SERIES

BY FREDERICK W. SARDESON

This paper forms pages 179-194 of this volume.

The following papers were read:

AGE AND STRATIGRAPHIC RELATIONS OF THE CHATTANOOGA BLACK SHALE

BY AMADEUS W. GRABAU

THE MEDINA SANDSTONE PROBLEM

BY AMADEUS W. GRABAU

PALEOGEOGRAPHY OF THE AMERICAN DEVONIC

BY CHARLES SCHUCHERT

Illustrated by a series of seven lantern slides.

The following paper was then read by title:

CARBONIFEROUS OF THE APPALACHIAN BASIN

BY JOHN J. STEVENSON

The full paper has been printed as pages 29-178 of this volume.

The following papers were read by title:

STRUCTURE OF THE DEEP RIVER TRIASSIC

BY COLLIER COBB

RED BEDS OF OKLAHOMA AND ADJACENT STATES

BY CHARLES NEWTON GOULD

STRUCTURE AND CORRELATION OF NEWARK TRAP ROCKS OF NEW JERSEY

BY J. VOLNEY LEWIS

This paper has been printed as pages 195-210 of this volume.

SOME RESULTS FROM THE STUDY OF THE CAMBRIAN BRACHIOPODA

BY CHARLES D. WALCOTT

The paper, which was an informal explanation of the results obtained in the preparation of a monograph on the Cambrian Brachiopoda, was illustrated by eighty of the plates, combined on twenty lantern slides, presenting the leading characteristics of the Cambrian Brachiopoda.

The next paper was read by title:

CRYPTOZOAN: GENERA, SPECIES, RELATIONSHIPS

BY HENRY M. SEELY

CRUSTACEAN FAUNA OF THE SHAWANGUNK GRIT IN EASTERN NEW YORK

BY JOHN M. CLARKE

ADDITIONAL FOOTPRINTS FROM THE CARBONIFEROUS SHALES OF MASSACHUSETTS

BY J. B. WOODWORTH

The reading of papers was declared finished.

RESOLUTION AS TO DIVISION OF MEETINGS INTO SECTIONS

It was moved that the Council be requested to consider the question of dividing each meeting into three sections for the reading of papers, consideration being had of the number and character of communications presented in the several branches of geologic science.

After discussion by A. W. Grabau, F. W. Sardeson, A. F. Foerste, and J. F. Kemp, the motion was passed.

Hearty votes of thanks were passed with reference to the hospitality offered the Society and the arrangements made for its meeting by Columbia University, the American Museum of Natural History, and the local committee.

The Society then adjourned.

Register of the New York Meeting, 1906

The following Fellows were in attendance at the meeting:

F. A. Adams.
H. M. Ami.
R. Arnold.
H. F. Bain.
R. M. Bagg.
J. Barrell.
G. H. Barton.
F. Bascom.
R. Bell.
C. P. Berkey.
A. Bibbins.
A. P. Brigham.
R. W. Brock.
A. H. Brooks.
E. R. Buckley.
S. Calvin.
H. D. Campbell.
W. B. Clark.
J. M. Clarke.
J. M. Clements.
C. Cobb.
A. P. Coleman.
W. O. Crosby.
W. Cross.
H. P. Cushing.
W. M. Davis.
J. S. Diller.
B. K. Emerson.
S. F. Emmons.
H. L. Fairchild.
N. M. Fenneman.
A. F. Foerste.
M. L. Fuller.
A. C. Gill.
C. H. Gordon.
A. W. Grabau.
H. E. Gregory.
F. P. Guilliver.
A. Hague.
C. W. Hayes.
A. Heilprin.
R. R. Hice.
R. T. Hill.
C. H. Hitchcock.
W. H. Hobbs.
J. A. Holmes.
T. C. Hopkins.
E. O. Hovey.
H. C. Hovey.
E. Howe.
E. E. Howell.
J. P. Iddings.
R. T. Jackson.
A. A. Julien.
A. Keith.
J. F. Kemp.
E. H. Kraus.
H. B. Kümmel.
G. F. Kunz.
A. C. Lane.
D. W. Langton.
W. T. Lee.
F. Leverett.
W. Libbey.
W. Lindgren.
H. D. McCaskey.
W J McGee.
W. McInnes.
W. D. Matthew.
F. J. H. Merrill.
G. P. Merrill.
A. M. Miller.
B. L. Miller.
W. G. Miller.
W. H. Niles.
H. F. Osborn.

F. B. Peck.
R. A. F. Penrose.
G. H. Perkins.
L. V. Pirsson.
J. H. Pratt.
A. H. Purdue.
H. F. Reid.
W. N. Rice.
C. H. Richardson.
H. Ries.
R. D. Salisbury.
F. W. Sardeson
C. Schuchert.
W. B. Scott.
E. A. Smith.
G. O. Smith.
A. C. Spencer.
J. W. Spencer.
J. Stanley-Brown.
T. W. Stanton.
J. J. Stevenson.
R. S. Tarr.
W. G. Tight.
E. O. Ulrich.
C. R. Van Hise.
F. R. Van Horn.
G. Van Ingen.
C. D. Walcott.
C. H. Warren.
H. S. Washington.
W. H. Weed.
F. B. Weeks.
L. G. Westgate.
D. White.
I. C. White.
R. P. Whitfield.
H. S. Williams.
B. Willis.
A. W. G. Wilson.
J. E. Wolff.
J. B. Woodworth.
F. E. Wright.
G. F. Wright.
W. S. Yeates.

Fellows-elect

R. S. Bassler.
F. G. Clapp.
H. F. Cleland.
J. A. Dresser.
E. Huntington.
T. A. Jaggar, Jr.
D. W. Johnson.

Total attendance, 127.

Session of the Cordilleran Section, Friday, December 28, 1906

The eighth annual meeting of the Cordilleran Section of the Society was called to order in room 71, Stanford University, California, at 10.50 a m, December 28, 1906, by the Chairman of the Section, Professor J. C. Branner.

The minutes of the seventh annual meeting were read and approved.

The following officers were elected for the ensuing year: A. C. Lawson, Chairman; George D. Louderback, Secretary, and G. K. Gilbert, Councillor.

The scientific program was then taken up and the following papers were presented and discussed:

NOTES ON THE STRUCTURE OF THE SANTA CRUZ RANGE, CALIFORNIA

BY J. F. NEWSOM

[*Abstract*]

The major fault lines of the range have northwest-southeast directions varying from north 20° west to north 45° west. Various movements have occurred along the major fault lines. Movement along some of the major lines has probably been to some extent lateral.

A secondary system of faults lying at angles of from north 60° west to north 75° west also occurs. These are reversed faults and are parallel with the principal axes of folding in the range.

The folds and secondary faults were probably formed by lateral movement and consequent crushing along the major fault lines.

NOTES ON THE TOPOGRAPHY OF THE SEWARD PENINSULA, ALASKA

BY J. F. NEWSOM

[*Abstract*]

The accumulation of ice, with its protective influence, has been an important factor in forming the rounded dome-like topography of the Seward peninsula. The protective influence of moss is also an important factor. In many places where small spots are free from moss, but surrounded by it, hogwallows are formed. Considerable hillocks are occasionally developed in old filled pond basins by the squeezing action of the freezing sands and gravels pushing up the unfrozen materials from below.

OCCURRENCE OF MIDDLE TERTIARY MAMMAL-BEARING BEDS IN NORTHWESTERN NEVADA

BY JOHN C. MERRIAM

This paper was published in Science, new series, volume xxvi, 1907, pages 380-382.

The meeting then adjourned for the noon recess.

The afternoon session began at 2.00 p m and the first paper was read by title:

NOTES ON SOME CALIFORNIA MINERALS

BY AUSTIN F. ROGERS

The following papers were then read and discussed:

*TRANSPORTATION OF DETRITUS BY YUBA RIVER**

BY G. K. GILBERT

[*Abstract*]

In the process by which running water transports detritus two factors are distinguished. The larger particles are rolled along the bottom, or else lifted

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momentarily, so as to make short leaps; they constitute the *bottom load.* The smaller are lifted far from the bottom, are sustained for long periods, and are distributed through the whole body of the current; they constitute the *suspended load.* The classification of load in each particular cause depends chiefly on velocity of current; a relatively swift stream will include in its suspended load relatively coarse detritus.

Many determinations have been made of the suspended load of streams, the method including (1) the measurement of the total quantity of water, and (2) the measurement of the ratio of load to water in samples taken from the stream. The determination of the bottom load is comparatively difficult, and there is much need of information as to its relative and absolute amount. The writer has taken advantage of an unusually favorable opportunity to measure the bottom load of the Yuba river, one of the tributaries of the Sacramento river in California.

The river issues from a mountain gorge at the Smartsville narrows, and thence to its mouth, a distance of 20 miles, traverses a valley. In consequence of a special condition brought about by hydraulic mining, it is now aggrading its channel in this part of its course. The growing deposit is of coarse gravel near the narrows, and of sand near the mouth, with gradual transition. During high floods the suspended load near the mouth of the river includes silt only; near the narrows it probably includes sand also, and possibly some small gravel.

In the summer of 1904 a dam 6 feet high was built at a point 5 miles below the narrows, where the channel is 1,500 feet wide; and the basin created by this dam was filled with detritus by the floods of the following winter and spring. In the summer of 1905 an addition was made to the dam, increasing its height 8 feet, and during the construction of this addition a contour map of the channel above the dam was made by the U. S. Geological Survey. The river remained low and the water clear until the following January, when a large flood occurred, lasting about one week. After the flood had passed the channel was resurveyed, and the two maps were afterward used to determine the quantity of detritus arrested. The character of the material deposited was investigated by means of pits and borings in the summer of 1906. During the flood the river was gaged to determine its discharge, and at the time of flood maximum the water was thoroughly sampled near the river mouth to determine the percentage of suspended load.

The discussion of the data thus obtained is not yet complete, but certain results of geologic bearing may be given at this time. All of the figures are approximate and subject to correction. The detritus which passed the mouth of the canyon during the flood of January, 1906, would cover a square mile to a depth of about 17 inches. The ratios of its chief components were: Silt, 24; sand, 24; gravel, 52. In this statement whatever sand was deposited in the interstices of the gravel is accounted with the gravel; by transferring it to the sand category the ratios are changed to: Silt, 24; sand, 34; gravel, 42. Near the river mouth, where the suspended load consisted of silt and the bottom load of sand, the ratio of bottom load to suspended load was about 1:1. Near the narrows, if the silt only be accounted as suspended load, its ratio to the bottom load was as 1:3; but if, as is probable, the sand also should be classed with the suspended load, the ratio is about 1:1.

A report on the subject is in preparation and will be published by the U. S. Geological Survey.

CROCIDOLITE-BEARING ROCKS OF THE CALIFORNIA COAST RANGES

BY GEORGE D. LOUDERBACK AND WM. J. SHARWOOD

[*Abstract*]

Although in no great quantity in any one place, crocidolite-bearing rocks have been found to be rather widely distributed in the Coast ranges of California. They may be classed as crocidolite-bearing cherts or quartzites and crocidolitic schists. A petrographical description was given, analysis presented, and mode of occurrence described. Evidence was offered that many if not all of the rocks are derived from radiolarian cherts, and that they are formed by the introduction of soda into the rock by solution.

PRIMITIVE CHARACTERS OF AMERICAN TRIASSIC ICHTHYOSAURS

BY JOHN C. MERRIAM

[*Abstract*]

The following characters generally appearing in the Triassic Ichthyosauria may be considered as survivals of characteristics of ancestral shore forms. Where the term "relatively" has been used the unexpressed comparison is with the Jurassic ichthyosaurs.

1. Limbs relatively large and first two segments relatively long.
2. Hind limbs relatively large.
3. Epipodial, metapodial, and phalangeal elements often elongated and with shafted median region.
4. Number of phalanges in each digit relatively small.
5. Number of digits not increased beyond five.
6. Pelvic elements relatively heavy; inferior elements much expanded; ischium and pubis not fused.
7. Skull generally relatively short compared with the length of the trunk region.
8. Jaws relatively short.
9. Maxillaries relatively long and premaxillaries relatively short.
10. Orbits relatively small in the earliest forms.
11. Vertebral centra averaging relatively long.
12. Anterior cervical vertebræ not fused.
13. Neural spines of vertebræ relatively thick.
14. Zygapophysial facets of upper arches in the anterior portion of the vertebral column not united or brought into the same plane.
15. Caudal intercentra large and united ventrally to form large Y-shaped chevrons.

FAUNA OF THE ASPHALT BEDS EXPOSED NEAR LOS ANGELES, CALIFORNIA

BY JOHN C. MERRIAM

This paper was published in Science, new series, volume xxiv, 1906, pp. 248-250.

ORIGIN OF SOUTH AMERICAN BEARS

BY JOHN C. MERRIAM

[*Abstract*]

The spectacle bear of South America represents a type known only from the western hemisphere. Its nearest allies are found in genus *Arctotherium*, occurring in the Quaternary of North and South America. Two views have been expressed concerning the origin of this type. The most nearly related forms are probably Asiatic.

The next three papers were read by title.

RECONNAISSANCE OF A RECENTLY DISCOVERED QUATERNARY CAVE DEPOSIT NEAR AUBURN, CALIFORNIA

BY E. L. FURLONG*

This paper was published in Science, new series, volume xxv, March, 1907, pages 392-394.

PHYSIOGRAPHIC CHANGES BEARING ON THE FAUNAL RELATIONSHIPS OF THE RUSSIAN AND SACRAMENTO RIVERS, CALIFORNIA

BY RULIFF S. HOLWAY†

This paper was published in Science, new series, volume xxvi, September, 1907, pages 382-383.

SAN PABLO FORMATION OF MIDDLE CALIFORNIA

BY CHAS. E. WEAVER*

The last paper of the day read and discussed was

TWO MOUNTAIN RANGES OF SOUTHERN CALIFORNIA

BY W. C. MENDENHALL

[*Abstract*]

The San Gabriel and the San Bernardino ranges are adjacent mountain masses, separated only by Cajon pass, and holding identical relations to the valley of southern California, and to the Mojave desert, lying to the north and east of it. They also are similarly related to the principal fault lines of this part of California, each of them being bounded along its southern margin by a major fracture, and one of them, the San Gabriel, certainly being limited in a similar way along its northern base, while less definite evidence indicates that the San Bernardino range is related in the same way to the desert lowland. Little is known of the geology of the interior of the two ranges, but that little indicates that in a broad way they contain similar masses of rocks, which probably differ but little in their ability to resist the attacks of erosional agents.

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* Introduced by J. C. Merriam.

† Introduced by George D. Louderback.

The similarities, however, disappear when the land forms are examined. The San Gabriel range has been completely dissected, resulting in thoroughly graded streams, sharp peaks, and knife-like ridges of discordant heights. No level areas at or near the summits, nor in the valley bottoms, exist within the mountain mass. The San Bernardino range contrasts sharply with its neighbor in these respects. Throughout its western end there is a strikingly level sky-line at an elevation of 5,000 feet or more. It contains many broad meadows, with lakes and playas, separated by smooth ridges. The topography of the central part is, in brief, topography of an old, well reduced type. About its periphery, however, topographic forms are strikingly new. Several of the streams are not reduced to grade; they meander through broad uplands in the central part of the range, then plunge over falls into steep canyons, which they follow to the valleys that border the ranges.

For these striking topographic differences there seems to be no adequate explanation in the rock types, in the relative masses of the ranges, in their relation to major drainage lines, nor in their relation to precipitation. It is concluded, therefore, that since each is a faulted, uplifted block, the San Bernardino mass, in which old topographic forms are well preserved, is much later in origin than its neighbor, the San Gabriel range, in which none of these old forms are now to be found.

The Section then adjourned for the day.

Session of the Cordilleran Section, Saturday, December 29, 1906

The meeting was called to order at 9.15 a m by the Chairman, and proceeded immediately to the reading and discussion of papers presented, as follows:

RELATION OF THE LOS ANGELES–OWENS RIVER AQUEDUCT TO THE FAULT LINES OF INYO AND SAN BERNARDINO COUNTIES

BY J. C. BRANNER

NOTES ON THE GEOLOGY OF THE MOUNT HAMILTON QUADRANGLE

BY JOHN F. NEWSOM AND RODERIC CRANDALL

[*Abstract*]

Discussion of the geological terranes present, their distribution and relations; of the main structural features, with special note of the larger faults and direction of movement; and of the relations of structural features to the topography.

CRETACEOUS STRATIGRAPHY OF THE SANTA CLARA VALLEY REGION

BY RODERIC CRANDALL*

[*Abstract*]

The fossils from the Cretaceous localities are listed according to their geographic distribution. Probabilities of the presence of Horsetown at mount

* Introduced by J. F. Newsom.

Diablo are discussed. The presence of Horsetown in northern California and the absence in southern California is taken as proof of a differential land movement on the west coast during mid-Cretaceous times.

PHYSIOGRAPHIC FEATURES OF SOUTH CENTRAL OREGON

BY G. A. WARING*

[*Abstract*]

This paper deals with the region forming the northwestern end of the Great basin. The basin range type of structure described by Gilbert and Russell is here well developed, the main features of the relief being the fault-scarps of the tilted monoclinal blocks. These, together with their associated undrained basins, now occupied by remnants of more extensive Quaternary lakes, and the peculiar lack of well defined drainage over much of the area are the three distinctive physiographic features. Low folding has also taken place and has resulted in certain definite topographic effects. In addition to the major scarps, there are numerous minor scarps, some of which may be faults, but others of which have evidently been produced by weathering agencies. The rock masses observed within the region are representative of various igneous effusive series exclusively. Here and there bosses of older rocks of medium basicity occur, but by far the greater part of the area is floored by a series of sheets of basalt and associated tuffs, which have been affected by the structures that have given rise to the striking physiographic features of the region.

The next paper was read by title:

THE METAMORPHIC AND CRYSTALLINE ROCKS OF THE SANTA CRUZ MOUNTAINS

BY SOLON SHEDD

The following were then read and discussed:

GENERAL GEOLOGICAL FEATURES OF THE TRUCKEE REGION EAST OF THE SIERRA NEVADA

BY GEORGE D. LOUDERBACK

[*Abstract*]

Contents

* Introduced by W. C. Mendenhall.

Area Described

The area described includes a belt lying north and south of the Truckee river and extending from the main east front of the Sierra Nevada just west of Verdi, Nevada, to the Truckee-Carson divide near Hazen. The chief topographic divisions, passing from west to east, are: (1) the Sierran fault front; (2) the Verdi-Long Valley depression at its base; (3) the line of elevation represented by the Carson range on the south and Peavine mountain and others to the north; (4) the depression of Spanish Springs valley, Truckee meadows, Washoe valley, etc.; (5) the Virginia range; (6) the depression of Pyramid lake, the lower Truckee valley, etc.; (7) the mountains lying between the Truckee and Humboldt regions. (For topography, see Sierraville, Reno, Carson, and Wadsworth sheets of the United States Geological Survey.)

Bedrock Complex

The Bedrock complex consists chiefly of granitic rocks, largely granites (in part granodiorites), with residual masses of more or less metamorphosed sedimentary and igneous rocks into which they were intruded. The chief sedimentary types are, perhaps, quartzites and mica-schists, including muscovite-schists. A petrographically interesting meta-dacite is found at intervals for at least 12 or 15 miles north of Reno. Limestone and slate are occasionally found, and to the south, near Mound House, gypsum.

The Bedrock complex is found in the Sierran front, in Peavine mountain, and in a number of the small ranges to the north and northeast of Reno, and in the Carson range to the south. Near Steamboat springs both sediments and intrusions have been mapped and described by Becker.*

With one or two exceptions, the Bedrock complex is exposed only west of the Virginia range. This range is made up of a great thickness of Tertiary igneous material which has so deeply buried the older rocks that they have not yet been exposed by the Truckee river, which has cut a canyon directly across the range over 2,000 feet deep. The pre-Tertiaries, however, rise to the surface in this range some miles south, in the vicinity of Virginia City. The Marble bluff at the south end of Pyramid lake is of limestone, presumably Triassic.

Judging from a comparison between the Bedrock complex here and that in the Sierran province immediately west, the Humboldt region to the east, and certain areas to the south, it is probable that the schists are Mesozoic, possibly in part Paleozoic, and the granitic intrusives post-Jurassic. There is absolutely no evidence suggesting the Archean age of the rocks of the Peavine Mountain area, although like several areas since proved Mesozoic, it was so marked by the Fortieth Parallel Survey and their mapping was recently copied on the map of Bulletin 208 of the United States Geological Survey. Until some evidence or suggestive line of reasoning indicates its presence, it is misleading to map any areas of northwestern Nevada as Archean.†

The chief folding of the Bedrock complex undoubtedly took place at the time of the extensive post-Jurassic orogenic disturbances that affected so strongly the regions just east and west of the Truckee country. The granites have

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* U. S. Geological Survey, Monograph xiii.

† See also Bull. Geol. Soc. Am., vol. 15, pp. 317, 335, 340.

been stripped of their covering over such large areas that the axes of folding are not generally determinable, but evidence so far observed consistently points to major axes not departing many degrees from north and south. This is in harmony with the structural lines of the pre-Tertiaries of adjoining areas.

The great Unconformity

After the folding and intrusion of the Bedrock complex follows a long period of erosion, during which the products of disintegration and decay were carried beyond the borders of this region and a country of comparatively low relief was produced. The succeeding rocks are frequently deposited on a plane granite floor, but in several places evidence of granite hills is obtainable. This erosion interval included the Cretaceous and lower Tertiary.

The Tertiary Lavas

Andesites

The most abundant and varied volcanics of the region are andesites, chiefly hornblende andesites, varying at one extreme to augite andesites, sometimes of basaltic texture and at the other to quartz-mica-hornblende andesites with well developed phenocrysts.

Along the Carson block and the upper Truckee the more common sequence is coarse andesitic breccia with finer ash layers lying directly on the granite and capped by hornblende andesite flows. Andesites also occur on the southern flank of Peavine mountain and in the low hills north and south of Reno; also in great abundance in the Virginia range. In these latter areas breccia is only occasionally present. In some parts of the Virginia range the andesites are amygdaloidal, and they often show the propylitic type of alteration, especially near Virginia City and in the Olinghouse Canyon district.

These various andesites are very similar to and are practically continuous with those of the Sierra Nevada and are presumably of the same age—late Miocene or early Pliocene. Although the most abundant of the volcanic series of this region and of the Sierra Nevada, evidences of craters are entirely lacking, and even the foci of eruption are not generally evident. On the upper slopes of Peavine mountain the granites are cut by a number of dikes identical lithologically with andesite flows lying on the lower slopes, and were apparently loci of eruptions in that area.

The andesites have often suffered alteration by solfataric action or mineralization. This generally occurs along faults which have been seats of deposition, the rising waters sometimes (1) impregnating a zone with sulphides and very little silica, sometimes (2) with silica and very little sulphides, sometimes (3) with both well developed. Occasionally calcite gangue is found. In the first case the mineralized zone may now appear on the surface as a belt of excessive decomposition showing the combined effects of oxidation and sulphuric acid (from the oxidized sulphides) action. The ground is soft and easily eroded, is bright red from iron oxide, or leached to various shades with white as the end result. Many of these belts carry low (at present noncommercial) values in gold and silver, but occasionally rather high. At the Wedekind mine several hundred dollars a ton in silver was found at the surface, due to secondary concentration. In general the most common original sulphide is pyrite, with occasionally galena and sometimes sphalerite.

The second type gives rise to silicified zones, which weather in prominent reefs. The silica occurs partly as a deposit in cracks or other open spaces with distinct crustification and often drusy structures, partly as a cement between the crushed fragments and particles of the rock and partly as a replacement of the rock, the original porphyritic structure often being visible in the silicified product. These three modes of deposition are commonly found in the same ledge. Many of these occur in low hills north of the Truckee meadows.

The Olinghouse Canyon mines are in fissured (commonly crushed and sheeted) zones in andesite and carry gold without much deposited gangue material. The best known deposits in these rocks are along the Comstock lode and need not here be described. They belong to the third type mentioned above.

RHYOLITES

The rhyolites (and geologically related dacites) occur to the north and northeast of Reno, and more abundantly in the Virginia range, where they vary from vitreous, sometimes perlitic, to lithoidal, often porphyritic, and occur both as lava flows and dikes. They are less abundant than the andesites. They may also be accompanied by mineralization as in the White Horse district. White Horse mountain is a stock of rhyolite, and dikes pass from it out into the surrounding andesites. Good values have been found in some of the dikes. Veins in rhyolite also occur to the south near Gold Hill.

BASALTS

The latest of the Tertiary eruptions are basalts. They are found about Steamboat springs, along the summit region of the Virginia range, and abundantly in the ranges just east of this. There is commonly evidence of some deformation before the outpouring of the basalts.

DISTRIBUTION OF TYPES

A noteworthy change takes place in the character of the predominant types of Tertiary lavas as we pass from west to east across the Truckee region. In the western part the andesites occupy the field almost to the exclusion of other types. In the central part, especially in the Virginia range, we get the greatest complex. The andesites show the greatest mineralogical varieties, and although still the dominant rock type they are accompanied by considerable quantities of rhyolite and basalt. To the east of the Virginia range the andesites practically disappear, and we have a broad area, forming the eastern edge of the Truckee region, but lying chiefly in the Humboldt region, which is characterized by a great thickness of rhyolite flows and tuffs overlain by caps of basalt.

Tertiary Sediments

The Tertiary sediments are entirely freshwater or subaerial. The greatest part has been included under the title Truckee beds. The type locality is the Kawsoh mountains and along the east edge of the Virginia range, at the eastern edge of the Truckee region. Other areas are found in the summit region of the Virginia mountains south of the Truckee river; in the Truckee meadows, especially flanking the Carson block and extending up the river to the Sierra fault front west of Verdi; along the west side of Spanish Springs valley; in

the valley northeast of Peavine mountain and running north in Long valley to the neighborhood of Honey Lake valley. It is very probable that many of the valley areas in which the beds are not now exposed really carry them overlain by Quaternary deposits. In several such places this has been demonstrated by shallow railroad grades, trenches, and wells.

These beds lie unconformably on the granites and other members of the Bedrock series, and consist largely of poorly cemented sands and clays, the former being sometimes gray and friable, sometimes charged with limonite, and occasionally nodular. The lateral corrasion of the Truckee river a few miles above Reno causes occasional landslides, that produce cliffs several hundred feet high, exposing beautiful sections of the stratification (plate 73).

Diatomaceous earth, frequently of great purity, is a characteristic member of the series and just west of Reno is about 400 feet thick. Besides diatom remains, it contains sponge spicules and a slight amount of mineral fragments. Fish remains are found in it east of the Virginia range. Some layers are ashy and carry small fragments of pumice and crystal (apparently pyroclastic) fragments of minerals of igneous rocks.

Current-bedded gravels, tuffs, and blue tuffaceous sandstones are common, especially in the lower part of the series near Verdi. We also find fossil leaves and lignite beds, the latter formed by leaf and twig accumulations (that is, drifted material) often intimately associated with laminæ or with a general admixture of volcanic ash. A shell limestone was observed in the Kawsoh mountains near Hazen.

These beds lie on the weathered surface of the andesites, but they precede the block faulting of the ranges, some areas being found in the valleys and some in the summit region of the Virginia and other ranges. They are characteristically disturbed by tilting and some folding, though except along fault planes they generally lie at moderate angles of dip, say from 10 to 40 degrees. The plant remains are of the broad leaf type (or reeds) and point to a lower altitude of the country at that time. These various relationships indicate that the beds may be upper Miocene or Pliocene.

An interesting section of the basal beds occurs a mile or two southwest of Reno. The lava dips under the sediments and carries a layer of pre-Truckee soil. The sediments show several alternations of distinct lake sediment and alluvial material or wash, each a few feet or yards thick. This seems to indicate a lake with considerable fluctuation in areal extent, and possibly therefore occupying an interior basin without outlet (at least part of the time) similar to the Quaternary Bonneville or Lahontan.

The eastern part of the Truckee region and the Humboldt region are characterized by thick rhyolitic ash accumulations. They may in part have accumulated subaerially on desert valleys, but in part were deposited in water and carry sand and pebble beds. Whether these should be associated with the Truckee beds or separated as a later series has not been determined.

Post-Tertiary orogenic Movements

At the end of the Tertiary or early in the Quaternary the acute deformation took place that gave rise to the present mountain ranges. Folding or bending movements were restricted in occurrence, the most characteristic movements being those of block faulting of the Basin Range type. Most commonly the

FIGURE 1.—PEAVINE MOUNTAIN FAULT BLOCK

Main scarp on right hand (northeast) side. Looking northwest from Reno

FIGURE 2.—LANDSLIDE IN TRUCKEE LAKE SANDS, WITH RIVER SAPPING ITS BASE

Looking southeast from near Laughtons. Photograph by G. J. Young

FAULT BLOCK AND LAKE BEDS, TRUCKEE REGION

faulting was accompanied by tilting, one slope of the range being the more or less eroded fault scarp, the other the tilted older surface, which often shows but slight relief. The faulting is determined by topographic form, by the relation of older structures to range front, and by the attitude and distribution of the lake beds, ash beds, or lavas, as the case may be.*

The areas of uplift (or downthrow), and therefore the fault scarps, generally strike north-south or at angles not far removed from that direction. High values are represented by the fault on west side of Spanish Springs valley, which strikes north 28 degrees east, and the Peavine fault, north 45 degrees west. Where short independent ranges are produced, as best developed in the country north of the Truckee meadows, they are generally not bounded on the north or south by faults, but the block is flexed so that its surface of deformation rises in a curve from the valley on the north and descends unbroken underneath the valley to the south, like the axis of an anticlinal fold.† A longitudinal curvature of the depressed portions is probably the rule, but rarely observable. An exceptional opportunity for observation is afforded by the depression between the north end of the Carson Range block and the Peavine Mountain block. The Carson range is a large block with high scarp on the east side, and rises to 10,800 feet in mount Rose. Going north it rapidly drops to the Truckee river (4,500 to 5,000 feet). On the river slope the lowering is about 4,000 feet in 4 miles. Peavine mountain is also a fault block with a scarp on its northeast side and tilted gently to the southwest. It rises to the height of 8,270 feet, and drops off to the Truckee river to the south at the rate of about 1,000 feet to the mile. The lower part of the depression between the two blocks is occupied by lake beds lying on the andesites and the whole folded into a syncline, with axis east and west, the Truckee River valley lying along this axis. In other words, the surface of deformation of the Carson block drops to the north in a curve somewhat sharper than usual and terminates the range; it then rises again from the valley and becomes the curved surface of deformation of Peavine mountain.

The principal fault scarps recognized, together with the present elevation of range summit above surface of valley at the base of the scarp, follow:

Range.	Scarp facing.	General strike.	Feet.
Sierra west of Verdi	East	North-south	3,400
State Line range	West	North-south	2,900
Peavine mountain	Northeast	North 45 degrees west	3,300
Small ranges northeast of Peavine	East	North 5 degrees east North 12 degrees east	2,000
Range west of Spanish Springs valley	South of east	North 28 degrees east	1,500
Carson range	East	North-south	5,500
Virginia range—			
By Truckee meadows	West	North-south	2,500
By lower Truckee valley	East	North 5 degrees west	4,000

It may be noted that the large blocks have faults closely approximating or practically running north-south. The fault differing most from this direction is the shortest one given in the table.

Secondary faults within the general range blocks are not uncommon, giving

* Methods already described in detail in Bull. Geol. Soc. Am., vol. 15, 1904, pp. 289-346.

† This was also pointed out for the Humboldt mountains, loc. cit., p. 338.

rise to benches* or small valleys with one side a fault scarp, that scarp most commonly showing a throw in like sense to the primary fault. In the Virginia range, where there are probably two primary faults, a graben was found bounded both east and west by fault scarps in part broken into steps. In some places, instead of a scarp formed by movement along a single plane, are found a series of step faults, which distribute the upper layer along the face of the scarp, making it appear as very much thicker than normal, or giving rise on distant view to doubt as to the existence of fault at that point. Such a front is found on the Carson range not far from Reno and on parts of the Virginia range.

Lake Lahontan

The lower Truckee River valley and other valleys east of the Virginia range were occupied by the Quaternary lake Lahontan and carry in their lower parts the practically horizontal and unconsolidated lake beds. The sides of these valleys are striated by the shorelines, with fresh cliffs, terraces, etcetera, and are prominently coated by the Lahontan calcareous tufas already described by Russell.†

We may note that the lake beds are found about 12 miles up the Truckee River canyon, showing that it had been cut even below its present level before lake Lahontan was formed. In the upper part of the canyon the stream flows on Tertiary volcanic bedrock.

The Truckee meadows were not reached by the Lahontan water level, but throughout that period, as at present, were occupied by the Truckee river and its floodplains. Well developed terraces have been cut in the lake beds at least up to 5,100 feet 5 miles west of Reno (700 feet above the river). Some of the terraces have but a thin veneer of river deposit, but one about 80 to 100 feet above the river is underlain by a thick deposit of coarse boulders.

The Truckee River

The Truckee river leaves the main Sierra front near Verdi, passes along the axial belt of the depressed area (syncline) between the end of the Carson range and the Peavine Mountain block, and flows out onto the main Truckee meadows. Crossing these, it strikes right across the slope of the Virginia range, which rises abruptly from the valley some 2,500 to 3,500 feet, and cuts by a deep canyon almost perpendicularly across the range, emerging on the depressed block to the east, where it turns north and follows the topographic (orogenic) control to Pyramid lake. If we could fill up the Truckee canyon, the river would flood the meadows and finally seek Pyramid lake to the northeast by a shorter route.

It seems very evident that the Truckee river is an antecedent stream, in existence before the present ranges, and that the Virginia mountains have been slowly raised across its course, the river being active enough to maintain its course, and for that distance at least (25 miles) remain independent of the orogenic control which is almost universal in this region.

It is probable that during the gradual uprising of the mountains the Truckee

* See figure illustrating subsidiary faulting in the Carson range, loc. cit., plate 16, and discussion, p. 341.

† U. S. Geological Survey, Monograph xi.

FIGURE 1.—GAP WHERE TRUCKEE RIVER LEAVES THE MEADOWS AND ENTERS THE VIRGINIA RANGE

Mountains rise 2,000 to 3,000 feet above the valley. Looking east. Photograph by G. J. Young

FIGURE 2.—PLEISTOCENE GRAVELS WEST OF RENO

Thirty-foot fault near center of section, its scarp destroyed by river planation. Aggradation shown here probably related to upward movement in Virginia range, which is visible in the distance

VIEWS ILLUSTRATINC HISTORY OF TRUCKEE RIVER

meadows were often flooded, and temporarily—perhaps for many years at a time—occupied by a lake. At present the river is flowing over volcanic bedrock at the entrance to the canyon, while the valley is occupied by alluvium and lake beds. The ground-water moving from the west has a level which gradually approaches the surface and appears above it in hollows, producing more or less marshy ground near the Virginia Range front. We have therefore what is practically an underground lake which, save for percolation into the bedrock, must discharge over the rim at the canyon opening. During periods of considerable water supply from the west the ground-water level rises above the ground and a certain area becomes flooded. Renewed faulting along the range front would quickly produce a "permanent" flooded area.

The Truckee River channel has occasionally been occupied or displaced by Quaternary basaltic lavas. One flow occurred in the canyon through the Virginia range. It extended clear across the canyon, and the river, hemmed in by hard volcanic walls, was forced to cut through it, and has left it as flat terraces projecting from the canyon walls.

About 10 miles west of Reno successive flows came down from the flanks of Peavine mountain and occupied a channel cut in Tertiary lake beds and andesites. In this case the river found it easier to cut through the lake beds, and now flows at the base of the basalt, which rises 450 feet in a striking cliff. A long basalt flow, now left as terraces, is to be found higher up the river near Truckee.

Two sets of hot springs, probably genetically connected with the acute post-Tertiary deformation, are found on the east flank of the Carson range (Steamboat springs) and about 5 miles west of Reno (Laughtons springs). Several wells sunk along the front of the Carson range have struck hot water, indicating other hot springs that do not reach the surface, but feed direct into the ground water.

The Quaternary river deposits are faulted just west of Reno sometimes as much as 30 feet, and scarps topographically very young are frequently observed. In gathering data concerning the San Francisco earthquake of 1906 information was obtained concerning small shocks felt distinctly at several towns, but rapidly dying away in distance and so circumscribed that they pointed to recent disturbance along the Virginia mountains. The most active part of the orogenic cycle inaugurated in the early Quaternary is probably passed, but the forces do not seem to have reached yet a condition of equilibrium.

The writer is indebted to Professor G. J. Young for three of the photographs used in the illustration of this paper.

A COLLECTION OF FOSSIL FISHES FROM NORTHEASTERN BRAZIL

BY J. C. BRANNER AND D. S. JORDAN

DIATOMS AS A SOURCE OF SILICA IN SEDIMENTARY BEDS

BY J. C. BRANNER

Adjournment was then taken until afternoon.

The Section reassembled and resumed its program at 2.40 p m, the following papers being presented and discussed:

GEOLOGICAL RECONNAISSANCE IN THE SAN JOAQUIN VALLEY

BY H. R. JOHNSON*

THE LATEST PHASE OF THE COLORADO RIVER PROBLEM

BY W. C. MENDENHALL

The Section then passed a vote of thanks to Stanford University for the use of its rooms and for other courtesies shown during the meeting.

The Section then adjourned sine die.

George D. Louderback,
Secretary.

Register of the Meeting of the Cordilleran Section

The following fellows were in attendance at the meeting:

J. C. Branner.
G. K. Gilbert.
A. C. Lawson.
G. D. Louderback.
W. C. Mendenhall.
J. C. Merriam.
J. F. Newsom.
Solon Shedd.

In attendance as visitors were:

E. P. Carey.
Roderic Crandall.
H. C. Hartzell.
L. M. Hoskins.
H. R. Johnson.
E. S. Larsen, Jr.
J. Perrin Smith.
G. A. Waring.
G. A. Wilcox.
G. J. Young.

* Introduced by W. C. Mendenhall.

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By H. P. Cushing, *Librarian*

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U. S. GRANT

3187. Copper and other Mineral Resources of Prince William Sound.
3188. Structural Relations of the Wisconsin Zinc and Lead Deposits.

C. H. HITCHCOCK

3189. The Bible and Recent Science.

GEORGE P. MERRILL

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Notes on the Composition and Structure of the Hendersonville, North Carolina, Meteorite.

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FELLOWS IN DECEMBER, 1907

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Cleveland Abbe, Jr., Ph. D., Mount Weather, Va. August, 1899.

Frank Dawson Adams, Ph. D., Montreal, Canada; Professor of Geology in McGill University. December, 1889.

George I. Adams, Sc. D., Corps of Mining Engineers, Lima, Peru. December, 1902.

José Guadalupe Aguilera, Director del Instituto Geologico de Mexico, City of Mexico, Mexico. August, 1896.

Truman H. Aldrich, M. E., 1739 P St. N. W., Washington, D. C. May, 1889.

Henry M. Ami, A. M., Geological Survey Office, Ottawa, Canada; Assistant Paleontologist on Geological and Natural History Survey of Canada. December, 1889.

Frank M. Anderson, B. A., M. S., 2604 Ætna Street, Berkeley, Cal. California State Mining Bureau. June, 1902.

Philip Argall, 728 Majestic Building, Denver, Colo.; Mining Engineer. August, 1896.

Ralph Arnold, Ph. D., Washington, D. C.; Geologic Aid, U. S. Geological Survey. December, 1904.

George Hall Ashley, M. E., Ph. D., Washington, D. C.; U. S. Geological Survey. August, 1895.

Harry Foster Bain, M. S., Champaign, Ill.; State Geologist. December, 1895.

Rufus Mather Bagg, Jr., Ph. D., 1048 Riverdale St., West Springfield, Mass.; Mining Geologist. December, 1896.

S. Prentiss Baldwin, 736 Prospect St., Cleveland, Ohio. August, 1895.

Sydney H. Ball, A. B., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1905.

Erwin Hinckley Barbour, Ph. D., Lincoln, Neb.; Professor of Geology, University of Nebraska, and Acting State Geologist. December, 1896.

Alfred Ernest Barlow, B. A., M. A., D. Sc., Ottawa, Canada; Mining Geologist. December, 1906.

Joseph Barrell, Ph. D., New Haven, Conn.; Assistant Professor of Geology. Yale University. December, 1902.

George H. Barton, B. S., Boston, Mass.; Curator, Boston Society of Natural History. August, 1890.

Florence Bascom, Ph. D., Bryn Mawr, Pa.; Professor of Geology, Bryn Mawr College. August, 1894.

Ray Smith Bassler, B. A., M. S., Ph. D., Washington, D. C., U. S. National Museum. December, 1906.

William S. Bayley, Ph. D., Urbana, Ill.; Assistant Professor of Geology, University of Illinois. December, 1888.

*George F. Becker, Ph. D., Washington, D. C., U. S. Geological Survey.

Joshua W. Beede, Ph. D., Bloomington, Ind.; Instructor in Geology, Indiana University. December, 1902.

Robert Bell, C. E., M. D., LL. D., Ottawa, Canada; Acting Director of the Geological and Natural History Survey of Canada. May, 1889.

Charles P. Berkey, Ph. D., New York city; Columbia University. August, 1901.

Samuel Walker Beyer, Ph. D., Ames, Iowa; Assistant Professor in Geology, Iowa Agricultural College. December, 1896.

Arthur B. Bibbins, Ph. B., Baltimore, Md.; Instructor in Geology, Woman's College. December, 1903.

Albert S. Bickmore, Ph. D., American Museum of Natural History, New York; Curator emeritus, Department of Public Instruction. December, 1889.

Irving P. Bishop, 109 Norwood Ave., Buffalo, N. Y.; Professor of Natural Science, State Normal and Training School. December, 1899.

John M. Boutwell, M. S., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1905.

John Adams Bownocker, D. Sc., Columbus, Ohio.; Professor of Inorganic Geology, Ohio State University. December, 1904.

*John C. Branner, Ph. D., Stanford University, Cal.; Professor of Geology in Leland Stanford, Jr., University.

Albert Perry Brigham, A. B., A. M., Hamilton, N. Y.; Professor of Geology and Natural History, Colgate University. December, 1893.

Reginald W. Brock, M. A., Ottawa, Canada; Geologist, Geological and Natural History Survey of Canada; Professor of Geology, School of Mining, Kingston. December, 1904.

Alfred Hulse Brooks, B. S., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1899.

Amos P. Brown, Ph. D., Philadelphia, Pa.; Professor of Mineralogy and Geology, University of Pennsylvania. December, 1905.

Ernest Robertson Buckley, Ph. D., Rolla, Mo.; State Geologist and Director of Bureau of Geology and Mines. June, 1902.

*Samuel Calvin, Iowa City, Iowa; Professor of Geology and Zoology in the State University of Iowa.

Henry Donald Campbell, Ph. D., Lexington, Va.; Professor of Geology and Biology in Washington and Lee University. May, 1889.

Marius R. Campbell, U. S. Geological Survey, Washington, D. C. August, 1892.

Franklin R. Carpenter, Ph. D., 1420 Josephine St., Denver, Colo.; Mining Engineer. May, 1889.

Ermine C. Case, Ph. D., Department of Geology, University of Michigan, Ann Arbor, Mich. December, 1901.

*T. C. Chamberlin, LL. D., Chicago, Ill.; Head Professor of Geology, University of Chicago.

Clarence Raymond Claghorn, B. S., M. E., Tacoma, Wash. August, 1891.

Frederick G. Clapp, S. B., Washington, D. C.; Geologic Aid, U. S. Geological Survey. December, 1905.

*William Bullock Clark, Ph. D., Baltimore, Md.; Professor of Geology in Johns Hopkins University; State Geologist.

John Mason Clarke, A. M., Albany, N. Y.; State Paleontologist. December, 1897.

Herdman F. Cleland, Ph. D., Williamstown, Mass.; Professor of Geology, Williams College. December, 1905.

J. Morgan Clements, Ph. D., 15 William St., New York city. December, 1894.

Collier Cobb, A. B., A. M., Chapel Hill, N. C.; Professor of Geology in University of North Carolina. December, 1894.

Arthur P. Coleman, Ph. D., Toronto, Canada; Professor of Geology, Toronto University, and Geologist of Bureau of Mines of Ontario. December, 1896.

George L. Collie, Ph. D., Beloit, Wis.; Professor of Geology in Beloit College. December, 1897.

Arthur J. Collier, A. M., S. B., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. June, 1902.

*Theodore B. Comstock, Sc. D., Los Angeles, Cal.; Mining Engineer.

Eugene Coste, B. ès-Sc., E. M., Toronto, Canada. December, 1906.

*Francis W. Cragin, Ph. D., Colorado Springs, Colo.; Professor of Geology in Colorado College.

Alja Robinson Crook, Ph. D., Springfield, Ill.; State Museum of Natural History. December, 1898.

*William O. Crosby, B. S., Boston Society of Natural History, Boston, Mass.; Assistant Professor of Mineralogy and Lithology in Massachusetts Institute of Technology.

WHITMAN CROSS, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

GARRY E. CULVER, A. M., 1104 Wisconsin St., Stevens Point, Wis. December, 1891.

EDGAR R. CUMINGS, Ph. D., Bloomington, Ind.; Assistant Professor of Geology, Indiana University. August, 1901.

*HENRY P. CUSHING, M. S., Adelbert College, Cleveland, Ohio; Professor of Geology, Western Reserve University.

REGINALD A. DALY, Ph. D., Ottawa, Canada; Geologist for Canada on International Boundary Commission. December, 1905.

*NELSON H. DARTON, United States Geological Survey, Washington, D. C.

*WILLIAM M. DAVIS, S. B., M. E., Cambridge, Mass.; Sturgis-Hooper Professor of Geology in Harvard University.

DAVID T. DAY, Ph. D., U. S. Geological Survey, Washington, D. C. August, 1891.

ORVILLE A. DERBY, M. S., Sao Paulo, Brazil; No. 80 Rua Visconde do Rio Branco. December, 1890.

*JOSEPH S. DILLER, B. S., U. S. Geological Survey, Washington, D. C.

EDWARD V. D'INVILLIERS, E. M., 506 Walnut St., Philadelphia, Pa. Dec., 1888.

RICHARD E. DODGE, A. M., Teachers' College, West 120th St., New York city; Professor of Geography in the Teachers' College. August, 1897.

NOAH FIELDS DRAKE, Ph. D., Tientsin, China; Professor of Geology in Imperial Tientsin University. December, 1898.

JOHN ALEXANDER DRESSER, B. A., M. A., Montreal, Canada; Principal of Prince Albert School. December, 1906.

CHARLES R. DRYER, M. A., M. D., Terre Haute, Ind.; Professor of Geography, Indiana State Normal School. August, 1897.

*EDWIN T. DUMBLE, 1306 Main St., Houston, Texas.

ARTHUR S. EAKLE, Ph. D., Berkeley, Cal.; Instructor in Mineralogy, University of California. December, 1899.

CHARLES R. EASTMAN, A. M., Ph. D., Cambridge, Mass.; In Charge of Vetebrate Paleontology, Museum of Comparative Zoology, Harvard University. December, 1895.

EDWIN C. ECKEL, B. S., C. E., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1905.

ARTHUR H. ELFTMAN, Ph. D., 706 Globe Building, Minneapolis, Minn. December, 1898.

*BENJAMIN K. EMERSON, Ph. D., Amherst, Mass.; Professor in Amherst College.

*SAMUEL F. EMMONS, A. M., E. M., U. S. Geological Survey, Washington, D. C.

JOHN EYERMAN, F. Z. S., Oakhurst, Easton, Pa. August, 1891.

HAROLD W. FAIRBANKS, B. S., Berkeley, Cal.; Geologist State Mining Bureau. August, 1892.

*HERMAN L. FAIRCHILD, B. S., Rochester, N. Y.; Professor of Geology in University of Rochester.

J. C. FALES, Danville, Ky.; Professor in Centre College. December, 1888.

OLIVER C. FARRINGTON, Ph. D., Chicago, Ill.; In charge of Department of Geology, Field Columbian Museum. December, 1895.

NEVIN M. FENNEMAN, Ph. D., Madison, Wis.; Professor of Geology, University of Wisconsin. December, 1904.

AUGUST F. FOERSTE, Ph. D., 417 Grand Ave., Dayton, Ohio; Teacher of Sciences. December, 1899.

WILLIAM M. FONTAINE, A. M., University of Virginia, Va.; Professor of Natural History and Geology in University of Virginia. December, 1888.

*PERSIFOR FRAZER, D. ès-Sc. Nat., 1082 Drexel Building, Philadelphia, Pa.; Professor of Chemistry in Horticultural Society of Pennsylvania.

*HOMER T. FULLER, Ph. D., Fredonia, N. Y.

Myron Leslie Fuller, S. B., U. S. Geological Survey, Washington, D. C. December, 1898.

Henry Stewart Gane, Ph. D., Santa Barbara, Cal. December, 1896.

Henry Gannett, S. B., A. Met. B., U. S. Geological Survey, Washington, D. C. December, 1891.

Russell D. George, A. B., A. M., Boulder, Colo.; Professor of Geology, University of Colorado. December, 1906.

*Grove K. Gilbert, A. M., LL. D., U. S. Geological Survey, Washington, D. C.

Adam Capen Gill, Ph. D., Ithaca, N. Y.; Assistant Professor of Mineralogy and Petrography in Cornell University. December, 1888.

L. C. Glenn, Ph. D., Nashville, Tenn.; Professor of Geology in Vanderbilt University. June, 1900.

Charles H. Gordon, Ph. D., University of Tennessee, Knoxville, Tenn. August, 1893.

Charles Newton Gould, A. M., Norman, Okla.; Professor of Geology, University of Oklahoma. December, 1904.

Amadeus W. Grabau, S. M., S. D., New York city; Professor of Paleontology, Columbia University. December, 1898.

Ulysses Sherman Grant, Ph. D., Evanston, Ill.; Professor of Geology, Northwestern University. December, 1890.

Herbert E. Gregory, Ph. D., New Haven, Conn.; Silliman Professor of Geology, Yale University. August, 1901.

George P. Grimsley, Ph. D., Morgantown, W. Va.; Assistant State Geologist, Geological Survey of West Virginia. August, 1895.

Leon S. Griswold, A. B., Rolla, Missouri. August, 1902.

Frederic P. Gulliver, Ph. D., Norwichtown, Conn. August, 1895.

Arnold Hague, Ph. B., U. S. Geological Survey, Washington, D. C. May, 1889.

*Christopher W. Hall, A. M., 803 University Ave., Minneapolis, Minn.; Professor of Geology and Mineralogy in University of Minnesota.

Gilbert D. Harris, Ph. B., Ithaca, N. Y.; Assistant Professor of Paleontology and Stratigraphic Geology, Cornell University. December, 1903.

John Burchmore Harrison, M. A., F. I. C., F. G. S., Georgetown, British Guiana; Government Geologist. June, 1902.

John B. Hastings, M. E., 1480 High St., Denver, Colo. May, 1889.

*Erasmus Haworth, Ph. D., Lawrence, Kans.; Professor of Geology, University of Kansas.

C. Willard Hayes, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

Richard R. Hice, B. S., Beaver, Pa. December, 1903.

*Eugene W. Hilgard, Ph. D., LL. D.; Berkeley, Cal.; Professor of Agriculture in University of California.

Frank A. Hill, Roanoke, Va. May, 1889.

*Robert T. Hill, B. S., 25 Broad St., New York city.

Richard C. Hills, Mining Engineer, Denver, Colo. August, 1894.

*Charles H. Hitchcock, Ph. D., LL. D., Hanover, N. H.; Professor of Geology in Dartmouth College.

William Herbert Hobbs, Ph. D., Ann Arbor, Mich.; Professor of Geology, University of Michigan; Assistant Geologist, U. S. Geological Survey. August, 1891.

*Levi Holbrook, A. M., P. O. Box 536, New York city.

Arthur Hollick, Ph. B., Bronx Park, New York; Assistant Curator, Department of Fossil Botany, New York Botanical Garden. August, 1893.

*Joseph A. Holmes, 6017 Cabanne Ave., Saint Louis, Mo.; State Geologist of North Carolina; In charge of investigation of fuels and structural materials, U. S. Geological Survey.

Thomas C. Hopkins, Ph. D., Syracuse, N. Y.; Professor of Geology, Syracuse University. December, 1894.

*Edmund Otis Hovey, Ph. D., American Museum of Natural History, New York city; Associate Curator of Geology.

*Horace C. Hovey, D. D., Newburyport, Mass.

Ernest Howe, Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1903.

*Edwin E. Howell, A. M., 612 Seventeenth St. N. W., Washington, D. C.

Lucius L. Hubbard, Ph. D., LL. D., Houghton, Mich. December, 1894.

Ellsworth Huntington, A. B., A. M., Milton, Mass. December, 1906.

Joseph P. Iddings, Ph. B., Professor of Petrographic Geology, University of Chicago, Chicago, Ill. May, 1889.

John D. Irving, Ph. D., South Bethlehem, Pa.; Professor of Geology, Lehigh University. December, 1905.

A. Wendell Jackson, Ph. B., 432 Saint Nicholas Ave., New York city. December, 1888.

Robert T. Jackson, S. D., 9 Fayerweather St., Cambridge, Mass.; Assistant Professor in Paleontology in Harvard University. August, 1894.

Thomas M. Jackson, C. E., S. D., Clarksburg, W. Va. May, 1889.

Thomas Agustus Jaggar, Jr., A. B., A. M., Ph. D., Cambridge, Mass.; Professor of Geology, Massachusetts Institution of Technology, Boston. December, 1906.

Mark S. W. Jefferson, A. M., Ypsilanti, Mich.; Professor of Geography, Michigan State Normal College. December, 1904.

Douglas Wilson Johnson, B. S., Ph. D., Cambridge, Mass.; Assistant Professor of Physiography, Harvard University. December, 1906.

Alexis A. Julien, Ph. D., Columbia College, New York city; Instructor in Columbia College. May, 1889.

Arthur Keith, A. M., U. S. Geological Survey, Washington, D. C. May, 1889.

*James F. Kemp, A. B., E. M., Columbia University, New York city; Professor of Geology.

Charles Rollin Keyes, Ph. D., 944 Fifth St., Des Moines, Iowa. August, 1890.

Edward M. Kindle, Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1905.

Frank H. Knowlton, M. S., Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey. May, 1889.

Edward Henry Kraus, Ph. D., Ann Arbor, Mich.; Junior Professor of Mineralogy, University of Michigan. June, 1902.

Henry B. Kummel, Ph. D., Trenton, N. J.; State Geologist. December, 1895.

*George F. Kunz, A. M. (Hon.), Ph. D. (Hon.), care of Tiffany & Co., Fifth avenue, at 37th street, New York city.

George Edgar Ladd, Ph. D., Rolla, Mo.; Director School of Mines. August, 1891.

J. C. K. Laflamme, M. A., D. D., Quebec, Canada; Professor of Mineralogy and Geology in University Laval, Quebec. August, 1890.

Alfred C. Lane, Ph. D., Lansing, Mich.; State Geologist of Michigan. December, 1889.

Daniel W. Langton, Ph. D., Fuller Building, New York city; Mining Engineer. December, 1889.

Andrew C. Lawson, Ph. D., Berkeley, Cal.; Professor of Geology and Mineralogy in the University of California. May, 1889.

Willis Thomas Lee, M. S., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1903.

Charles K. Leith, Ph. D., Madison, Wis.; Professor of Geology, University of Wisconsin; Assistant Geologist, U. S. Geological Survey. December, 1902.

ARTHUR G. LEONARD, Ph. D., Grand Forks, N. Dak.; Professor of Geology and State Geologist, State University of North Dakota. December, 1901.

FRANK LEVERETT, B. S., Ann Arbor, Mich.; Geologist, U. S. Geological Survey. August, 1890.

JOSEPH VOLNEY LEWIS, B. E., S. B., New Brunswick, N. J.; Professor of Geology, Rutgers College. December, 1906.

WILLIAM LIBBEY, Sc. D., Princeton, N. J.; Professor of Physical Geography in Princeton University. August, 1899.

WALDEMAR LINDGREN, M. E., U. S. Geological Survey, Washington, D. C. August, 1890.

GEORGE DAVIS LOUDERBACK, Ph. D., Associate Professor of Geology, University of California, Berkeley, Cal. June, 1902.

ROBERT H. LOUGHRIDGE, Ph. D., Berkeley, Cal.; Assistant Professor of Agricultural Chemistry in University of California. May, 1889.

ALBERT P. LOW, B. S., Ottawa, Canada; Geologist, Geological Survey of Canada. December, 1905.

THOMAS H. MACBRIDE, A. M., Iowa City, Iowa; Professor of Botany in the State University of Iowa. May, 1889.

HIRAM DEYER MCCASKEY, B. S., U. S. Geological Survey, Washington, D. C. December, 1904.

RICHARD G. MCCONNELL, A. B., Geological Survey Office, Ottawa, Canada; Geologist on Geological and Natural History Survey of Canada. May, 1889.

JAMES RIEMAN MACFARLANE, A. B., 100 Diamond St., Pittsburg, Pa. August 1891.

*W J MCGEE, LL. D., Director Public Museum, Saint Louis, Mo.

WILLIAM MCINNES, A. B., Geological Survey Office, Ottawa, Canada; Geologist, Geological and Natural History Survey of Canada. May, 1889.

PETER MCKELLAR, Fort William, Ontario, Canada. August, 1890.

CURTIS F. MARBUT, A. M., State University, Columbia, Mo.; Instructor in Geology and Assistant on Missouri Geological Survey. August, 1897.

VERNON F. MARSTERS, A. M., Lima, Peru. August, 1892.

GEORGE CURTIS MARTIN, Ph. D., Washington, D. C., U. S. Geological Survey. June, 1902.

EDWARD B. MATHEWS, Ph. D., Baltimore, Md.; Instructor in Petrography in Johns Hopkins University. August, 1895.

W. D. MATTHEW, Ph. D., New York city; Associate Curator in Vertebrate Paleontology, American Museum of Natural History. December, 1903.

P. H. MELL, M. E., Ph. D., Clemson College, S. C.; President of Clemson College. December, 1888.

WARREN C. MENDENHALL, B. S., 1108 Braly Building, Los Angeles, Cal.; Geologist, U. S. Geological Survey. June, 1902.

JOHN C. MERRIAM, Ph. D., Berkeley, Cal.; Instructor in Paleontology in University of California. August, 1895.

*FREDERICK J. H. MERRILL, Ph. D., New Rochelle, N. Y.; Consulting Geologist.

GEORGE P. MERRILL, Ph. D., U. S. National Museum, Washington, D. C.; Curator of Department of Lithology and Physical Geology. December, 1888.

ARTHUR M. MILLER, A. M., Lexington, Ky.; Professor of Geology, State University of Kentucky. December, 1897.

BENJAMIN L. MILLER, Ph. D., South Bethlehem, Pa.; Professor of Geology, Lehigh University. December, 1904.

WILLET G. MILLER, M. A., Toronto, Canada; Provincial Geologist of Ontario. December, 1902.

HENRY MONTGOMERY, Ph. D., Toronto, Canada; Curator of Museum, University of Toronto. December, 1904.

*Frank L. Nason, A. B., West Haven, Conn.

David Hale Newland, B. A., Albany, N. Y.; Assistant State Geologist. December, 1906.

John F. Newsom, Ph. D., Stanford University, Cal.; Associate Professor of Mining. December, 1899.

William H. Niles, Ph. B., M. A., Boston, Mass.; Professor, Emeritus, of Geology, Massachusetts Institute of Technology; Professor of Geology, Wellesley College. August, 1891.

William H. Norton, M. A., Mount Vernon, Iowa; Professor of Geology in Cornell College. December, 1895.

Charles J. Norwood, Lexington, Ky.; Professor of Mining, State College of Kentucky. August, 1894.

Ida Helen Ogilvie, A. B., Ph. D., New York city; Tutor in Geology, Barnard College, Columbia University. December, 1906.

Cleophas C. O'Harra, Ph. D., Rapid City, S. Dak.; Professor of Mineralogy and Geology, South Dakota School of Mines. December, 1904.

Ezequiel Ordonez, 2 a General Prine, Mexico, D. F., Mex. August, 1896.

*Amos O. Osborn, Waterville, Oneida county, N. Y.

Henry F. Osborn, Sc. D., Columbia University, New York city; Professor of Zoology, Columbia University. August, 1894.

Charles Palache, B. S., University Museum, Cambridge, Mass.; Instructor in Mineralogy, Harvard University. August, 1897.

William A. Parks, B. A., Ph. D., Toronto, Canada; Associate Professor of Geology, University of Toronto. December, 1906.

*Horace B. Patton, Ph. D., Golden, Colo.; Professor of Geology and Mineralogy in Colorado School of Mines.

Frederick B. Peck, Ph. D., Easton, Pa.; Professor of Geology and Mineralogy, Lafayette College. August, 1901.

Richard A. F. Penrose, Jr., Ph. D., 460 Bullitt Building, Philadelphia, Pa. May, 1889.

George H. Perkins, Ph. D., Burlington, Vt.; State Geologist; Professor of Geology, University of Vermont. June, 1902.

Joseph H. Perry, 276 Highland St., Worcester, Mass. December, 1888.

Louis V. Pirsson, Ph. D., New Haven, Conn.; Professor of Physical Geology, Sheffield Scientific School of Yale University. August, 1894.

*Julius Pohlman, M. D., University of Buffalo, Buffalo, N. Y.

Joseph Hyde Pratt, Ph. D., Chapel Hill, N. C.; Mineralogist, North Carolina Geological Survey. December, 1898.

*Charles S. Prosser, M. S., Columbus, Ohio; Professor of Geology in Ohio State University.

*Raphael Pumpelly, U. S. Geological Survey, Dublin, N. H.

Albert Homer Purdue, B. A., Fayetteville, Ark.; Professor of Geology, University of Arkansas. December, 1904.

Frederick Leslie Ransome, Ph. D., Washington, D. C.; Geologist, U. S. Geological Survey. August, 1895.

Harry Fielding Reid, Ph. D., Baltimore, Md.; Professor of Geological Physics, Johns Hopkins University. December, 1892.

William North Rice, Ph. D., LL. D., Middletown, Conn.; Professor of Geology in Wesleyan University. August, 1890.

Charles H. Richardson, Ph. D., Syracuse, N. Y.; Assistant Professor of Geology and Mineralogy, Syracuse University. December, 1899.

Heinrich Ries, Ph. D., Cornell University, Ithaca, N. Y.; Professor of Economic Geology. December, 1893.

Rudolph Ruedemann, Ph. D., Albany, N. Y.; Assistant State Paleontologist. December, 1905.

Orestes H. St. John, Raton, N. Mex. May, 1889.

*Rollin D. Salisbury, A. M., Chicago, Ill.; Professor of General and Geographic Geology in University of Chicago.

Frederick W. Sardeson, Ph. D., Assistant Professor of Geology, University of Minnesota, Minneapolis, Minn. December, 1892.

Frank C. Schrader, M. S., A. M., U. S. Geological Survey, Washington, D. C. August, 1901.

Charles Schuchert, New Haven, Conn.; Professor of Paleontology, Yale University. August, 1895.

William B. Scott, Ph. D., 56 Bayard Ave., Princeton, N. J.; Blair Professor of Geology in College of New Jersey. August, 1892.

Arthur Edmund Seaman, B. S., Houghton, Mich.; Professor of Mineralogy and Geology, Michigan College of Mines. December, 1904.

Henry M. Seely, M. D., Middlebury, Vt.; Professor of Geology in Middlebury College. May, 1899.

Elias H. Sellards, Ph. D., Tallahassee, Fla.; State Geologist. December, 1905.

George Burbank Shattuck, Ph. D., Poughkeepsie, N. Y.; Professor of Geology in Vassar College. August, 1899.

Solon Shedd, A. B., Pullman, Wash.; Professor of Geology and Mineralogy, Washington Agricultural College. December, 1904.

Edward M. Shepard, Sc. D., Springfield, Mo.; Professor of Geology, Drury College. August, 1901.

Will H. Sherzer, M. S., Ypsilanti, Mich.; Professor in State Normal School. December, 1890.

Bohumil Shimek, C. E., M. S., Iowa City, Iowa; Professor of Physiological Botany, University of Iowa. December, 1904.

*Frederick W. Simonds, Ph. D., Austin, Texas; Professor of Geology in University of Texas.

William John Sinclair, B. S., Ph. D., Princeton, N. J.; Instructor in Princeton University. December, 1906.

*Eugene A. Smith, Ph. D., University, Tuscaloosa county, Ala.; State Geologist and Professor of Chemistry and Geology in University of Alabama.

Frank Clemes Smith, E. M., Richland Center, Wis.; Mining Engineer. December, 1898.

George Otis Smith, Ph. D., Washington, D. C.; Director, U. S. Geological Survey. August, 1897.

William S. T. Smith, Ph. D., 749 N. Lake St., Reno, Nev.; Associate Professor of Geology and Mineralogy, University of Nevada. June, 1902.

*John C. Smock, Ph. D., Trenton, N. J.

Charles H. Smyth, Jr., Ph. D., Clinton, N. Y.; Professor of Geology in Hamilton College. August, 1892.

Henry L. Smyth, A. B., Cambridge, Mass.; Professor of Mining and Metallurgy in Harvard University. August, 1894.

Arthur Coe Spencer, B. S., Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1896.

*J. W. Spencer, Ph. D., 2019 Hillyer Place, Washington, D. C.

Josiah E. Spurr, A. B., A. M., U. S. Geological Survey, Washington, D. C. December, 1894.

Joseph Stanley-Brown, Cold Spring Harbor, Long Island, N. Y. August, 1892.

Timothy William Stanton, B. S., U. S. National Museum, Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey. August, 1891.

*John J. Stevenson, Ph. D., LL. D., New York University; Professor of Geology in the New York University.

WILLIAM J. SUTTON, B. S., E. M., Victoria, B. C.; Geologist to E. and N. Railway Co. August, 1901.

JOSEPH A. TAFF, B. S., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1895.

JAMES E. TALMAGE, Ph. D., Salt Lake City, Utah; Professor of Geology in University of Utah. December, 1897.

RALPH S. TARR, Cornell University, Ithaca, N. Y.; Professor of Dynamic Geology and Physical Geography. August, 1890.

FRANK B. TAYLOR, Fort Wayne, Ind. December, 1895.

WILLIAM G. TIGHT, M. S., Albuquerque, N. Mex.; President and Professor of Geology, University of New Mexico. August, 1897.

*JAMES E. TODD, A. M., 1000 Illinois St., Lawrence, Kas.; Assistant Geologist, U. S. Geological Survey.

*HENRY W. TURNER, B. S., 508 California St., San Francisco, Cal.

JOSEPH B. TYRRELL, M. A., B. Sc., 9 Toronto St., Toronto, Canada. May, 1889.

JOHAN A. UDDEN, A. M., Rock Island, Ill.; Professor of Geology and Natural History in Augustana College. August, 1897.

EDWARD O. ULRICH, D. Sc., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1903.

*WARREN UPHAM, A. M.. Librarian Minnesota Historical Society, Saint Paul, Minn.

*CHARLES R. VAN HISE, M. S., Ph. D., Madison, Wis.; President University of Wisconsin; Geologist, U. S. Geological Survey.

FRANK ROBERTSON VAN HORN, Ph. D., Cleveland, Ohio; Professor of Geology and Mineralogy, Case School of Applied Science. December, 1898.

GILBERT VAN INGEN, Princeton, N. J.; Curator of Invertebrate Paleontology and Assistant in Geology, Princeton University. December, 1904.

THOMAS WAYLAND VAUGHN, B. S., A. M., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1896.

ARTHUR CLIFFORD VEACH, Washington, D. C.; Geologist, U. S. Geological Survey. December, 1906.

*ANTHONY W. VODGES, San Diego, Cal.; Captain Fifth Artillery, U. S. Army.

*M. EDWARD WADSWORTH, Ph. D., State College, Pa.; State Geologist, Pa.; Dean of the School of Mines and Metallurgy and Professor of Mining and Geology in the Pennsylvania State College, and Dean of the School of Mines and Professor of Mining and Geology in the Western University of Pennsylvania, Pittsburg, Pa.

*CHARLES D. WALCOTT, LL. D., Washington, D. C.; Secretary Smithsonian Institution.

THOMAS L. WALKER, Ph. D., Toronto, Canada; Professor of Mineralogy and Petrography, University of Toronto. December, 1903.

CHARLES H. WARREN, Ph. D., Boston, Mass.; Instructor in Geology, Massachusetts Institute of Technology. December, 1901.

HENRY STEPHENS WASHINGTON, Ph. D., Locust, Monmouth Co., N. J.; August, 1896.

THOMAS L. WATSON, Ph. D., Charlottesville, Va.; Professor of Geology in University of Virginia. June, 1900.

WALTER H. WEED, E. M., Norwalk, Conn. May, 1889.

FRED. BOUGHTON WEEKS, Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1903.

SAMUEL WEIDMAN. Ph. D., Madison, Wis.; Geologist, Wisconsin Geological and Natural History Survey. December, 1903.

STUART WELLER, B. S., Chicago, Ill.; Assistant Professor of Paleontologic Geology, University of Chicago. June, 1900.

LEWIS G. WESTGATE, Ph. D., Delaware, Ohio; Professor of Geology, Ohio Wesleyan University.

Thomas C. Weston, 591 Saint John St., Quebec, Canada. August, 1893.

David White, B. S., U. S. National Museum, Washington, D. C.; Geologist, U. S. Geological Survey, Washington, D. C. May, 1889.

*Israel C. White, Ph. D., Morgantown, W. Va.

*Robert P. Whitfield, A. M., American Museum of Natural History, 77th St. and 8th Ave., New York city; Curator of Geology and Paleontology.

Frank A. Wilder, Ph. D., North Holston, Smyth Co., Va. December, 1905.

*Edward H. Williams, Jr., A. C., E. M., Andover, Mass.

*Henry S. Williams, Ph. D., Ithaca, N. Y.; Professor of Geology and Head of Geological Department, Cornell University.

Ira A. Williams, M. Sc., Ames, Iowa; Teacher Iowa State College. December, 1905.

Bailey Willis, U. S. Geological Survey, Washington, D. C. December, 1889.

Samuel W. Williston, Ph. D., M. D., Chicago, Ill.; Professor of Paleontology, University of Chicago. December, 1889.

Arthur B. Willmott, M. A., Sault Ste. Marie, Ontario, Canada. December, 1899.

Alfred W. G. Wilson, Ph. D., 197 Park Ave., Montreal, Ontario, Canada; Mining Geologist. June, 1902.

Alexander N. Winchell, Doct. U. Paris, Madison, Wis.; Professor of Geology and Mineralogy, University of Wisconsin. August, 1901.

*Horace Vaughn Winchell, Saint Paul, Minn.; Geologist for the Great Northern Railway Company.

*Newton H. Winchell, A. M., Minneapolis, Minn.

*Arthur Winslow, B. S., 84 State St., Boston, Mass.

John E. Wolff, Ph. D., Harvard University, Cambridge, Mass.; Professor of Petrography and Mineralogy in Harvard University and Curator of the Mineralogical Museum. December, 1889.

Joseph E. Woodman, S. D., Halifax, N. S.; Assistant Professor of Geology and Mineralogy, Dalhousie University. December, 1905.

Robert S. Woodward, C. E., Washington, D. C.; President of the Carnegie Institution of Washington. May, 1889.

Jay B. Woodworth, B. S., 24 Langdon St., Cambridge, Mass.; Assistant Professor of Geology, Harvard University. December, 1895.

Frederic E. Wright, Ph. D., U. S. Geological Survey, Washington, D. C. December, 1903.

*G. Frederick Wright, D. D., Oberlin, Ohio; Professor in Oberlin Theological Seminary.

William S. Yeates, A. B., A. M., Atlanta, Ga.; State Geologist of Georgia. August, 1894.

George A. Young, Ph. D., Ottawa, Canada; Geologist, Geological Survey of Canada. December, 1905.

FELLOWS DECEASED

*Indicates Original Fellow (see article III of Constitution)

*Charles A. Ashburner, M. S., C. E. Died December 24, 1889.

Charles E. Beecher, Ph. D. Died February 14, 1904.

Amos Bowman. Died June 18, 1894.

*J. H. Chapin, Ph. D. Died March 14, 1892.

*Edward W. Claypole, D. Sc. Died August 17, 1901.

George H. Cook, Ph. D., LL. D. Died September 22, 1889.

*Edward D. Cope, Ph. D. Died April 12, 1897.

ANTONIO DEL CASTILLO. Died October 28, 1895.
*JAMES D. DANA, LL. D. Died April 14, 1895.
GEORGE M. DAWSON, D. Sc. Died March 2, 1901.
Sir J. WILLIAM DAWSON, LL. D. Died November 19, 1899.
*WILLIAM B. DWIGHT, Ph. B. Died August 29, 1906.
*GEORGE H. ELDRIDGE, A. B. Died June 29, 1905.
*ALBERT E. FOOTE. Died October 10, 1895.
N. J. GIROUX, C. E. Died November 30, 1890.
*JAMES HALL, LL. D. Died August 7, 1898.
JOHN B. HATCHER, Ph. B. Died July 3, 1904.
*ROBERT HAY. Died December 14, 1895.
*ANGELO HEILPRIN. Died July 17, 1907.
DAVID HONEYMAN, D. C. L. Died October 17, 1889.
THOMAS STERRY HUNT, D. Sc., LL. D. Died February 12, 1892.
*ALPHEUS HYATT, B. S. Died January 15, 1902.
*JOSEPH F. JAMES, M. S. Died March 29, 1897.
WILBUR C. KNIGHT, B. S., A. M. Died July 28, 1903.
RALPH D. LACOE. Died February 5, 1901.
*JOSEPH LE CONTE, M. D., LL. D. Died July 6, 1901.
*J. PETER LESLEY, LL. D. Died June 2, 1903.
HENRY MCCALLEY, A. M., C. E. Died November 20, 1904.
OLIVER MARGY, LL. D. Died March 19, 1899.
OTHNIEL C. MARSH, Ph. D., LL. D. Died March 18, 1899.
JAMES E. MILLS, B. S. Died July 25, 1901.
*HENRY B. NASON, M. D., Ph. D., LL. D. Died January 17, 1895.
*PETER NEFF, M. A. Died May 11, 1903.
*JOHN S. NEWBERRY, M. D., LL. D. Died December 7, 1892.
*EDWARD ORTON, Ph. D., LL. D. Died October 16, 1899.
*RICHARD OWEN, LL. D. Died March 24, 1890.
SAMUEL L. PENFIELD. Died August 14, 1906.
*FRANKLIN PLATT. Died July 24, 1900.
*WILLIAM H. PETTEE, A. M. Died May 26, 1904.
*JOHN WESLEY POWELL, LL. D. Died September 23, 1902.
*ISRAEL C. RUSSELL, LL. D. Died May 1, 1906.
*JAMES M. SAFFORD, M. D., LL. D. Died July 3, 1907.
*CHARLES SCHAEFFER, M. D. Died November 23, 1903.
*NATHANIEL S. SHALER, LL. D. Died April 10, 1906.
CHARLES WACHSMUTH. Died February 7, 1896.
THEODORE G. WHITE, Ph. D. Died July 7, 1901.
*GEORGE H. WILLIAMS, Ph. D. Died July 12, 1894.
*J. FRANCIS WILLIAMS, Ph. D. Died November 9, 1891.
*ALEXANDER WINCHELL, LL. D. Died February 19, 1891.
ALBERT A. WRIGHT, Ph. D. Died April 2, 1905.

Summary

Original Fellows	60
Elected Fellows	235
Membership	295
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